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Betting on Climate Policy: Using Prediction Markets to Address Global Warming

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Global warming, sea level rise, and extreme weather events have made climate change a top priority for policymakers across the globe. But which policies are best suited to tackle the enormous challenges presented by our changing climate? This Article proposes that policymakers turn to prediction markets to answer that crucial question. Prediction markets have a strong track record of outperforming other forecasting mechanisms across a wide range of contexts — from predicting election outcomes and economic trends to guessing Oscar winners. In the context of climate change, market participants could, for example, bet on important climate outcomes conditioned on the adoption of particular policies. These prediction markets would aggregate policy-relevant information from a variety of sources to improve upon existing decision-making methods, including expert deliberation, peer review, and cost-benefit analysis. Prediction markets also have the potential to overcome resistance to climate change mitigation efforts, particularly among market-oriented conservatives. We explain how both the federal and state governments could use prediction markets to help resolve high-profile controversies, such as how best to allocate subsidies to promote clean technology innovation and which policy strategy promises the greatest reduction in carbon emissions.

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TABLE OF CONTENTS

INTRODUCTION

The question of how to address climate change is a difficult one. Most experts agree that the United States should use a carbon tax or cap-and-trade program to place a price on the carbon emissions that drive global warming.[1] In the short term, however, pricing carbon may be politically impossible due to resistance from industry, voters, and conservative politicians.[2] As a result, some argue for second-best policies that are less ambitious, but more politically palatable,[3] such as federal fuel-efficiency standards for automobile manufacturers and state-level renewable portfolio standards for electric utilities. Skeptics, however, maintain that a second-best policy strategy will cost too much and likely prove ineffective.[4]

Even if pricing carbon were to become politically feasible, complementary policies might still be needed to effectively mitigate climate change. In particular, some experts argue that the government should heavily subsidize innovation in clean technologies to facilitate an economy-wide shift away from fossil fuels and toward renewable sources of energy.[5] Skeptics, however, cite to past failures and claim that politicians would use these "green subsidies" to reward favored special interests rather than to benefit the environment.[6]

[1] *See, e.g.*, NICHOLAS STERN, THE ECONOMICS OF CLIMATE CHANGE: THE STERN REVIEW xviii (2007) (explaining that taxing carbon is an effective economic solution to excessive carbon emissions); Adam B. Jaffe et al., *A Tale of Two Market Failures: Technology and Environmental Policy*, 54 ECOLOGICAL ECON. 164, 165, 169 (2005); *cf.* Atanas Kolev & Armin Riess, *Environmental and Technology Externalities: Policy and Investment Implications*, 12 EUR. INV. BANK PAPERS, no. 2, 2007, at 134, 137, 140 (stating that "the optimal outcome" can be met either by an emissions tax high enough to "fully internalise the economic cost of emissions" or by supplementing a lower tax rate "with direct technology support").

[2] *See* Felix Mormann, *Requirements for a Renewables Revolution*, 38 ECOLOGY L.Q. 903, 930-32 (2011) [hereinafter *Renewables Revolution*] (discussing the political economy obstacles for carbon pricing policies).

[3] For a discussion of the pros and cons of this approach, see Jonathan M. Gilligan & Michael P. Vandenbergh, *Accounting for Political Feasibility in Climate Instrument Choice*, 32 VA. ENVTL. L.J. 1, 5-26 (2014).

[4] *See, e.g.*, Bjorn Lomborg, *Impact of Current Climate Proposals*, 7 GLOBAL POL'Y 109, 111-17 (2016) (arguing that several major climate policy proposals will likely prove ineffective).

[5] *See, e.g.*, Zachary Liscow & Quentin Karpilow, *Innovation Snowballing and Climate Law*, 95 WASH. U. L. REV. 387, 389, 393 (2017) (making the case that "innovation snowballing" warrants greater government involvement in the promotion of clean tech innovation).

[6] *See, e.g.*, MICHAEL J. GRAETZ, THE END OF ENERGY: THE UNMAKING OF AMERICA'S ENVIRONMENT, SECURITY, AND INDEPENDENCE 187-95 (2011); CHARLES WEISS & WILLIAM B. BONVILLIAN, STRUCTURING AN ENERGY TECHNOLOGY REVOLUTION 209 (2009)

Remarkably, these climate policy debates often turn not so much on ideology or values, but instead on predictions about the future. Advocates for a given policy make their case by forecasting that the policy's benefits will exceed its costs while opponents forecast the opposite. Because of the uncertainty inherent in these forecasts, each side can claim that the other is misguided, biased, or corrupt, frequently leading to irresolvable disagreement and policy gridlock.

This Article argues that prediction markets offer hope for an escape from this stalemate. Prediction markets are "designed and run for the primary purpose of mining and aggregating information scattered among traders and subsequently using this information in the form of market values in order to make predictions about specific future events."[7] In recent years, these markets have garnered increased media attention following the proliferation of online betting exchanges that allow participants ("traders") to bet on whether certain events will occur in the future. In the simplest type of prediction market, traders buy a contract that pays $1 if the designated event happens, say the Democratic candidate wins the presidency. In more complex conditional prediction markets, traders bet that event *x* will happen contingent on some other event *y*. Conditional markets are common in the context of presidential elections.[8] For example, a prediction market contract for the 2020 presidential election might pay $1 if the Democratic nominee wins, with bets called off unless the nominee is Elizabeth Warren. If such a contract trades for $0.55, then we can interpret its price as the market's prediction that if Elizabeth Warren is the Democratic nominee, she has a fifty-five percent chance of winning the election.[9]

(observing that special interests can threaten to overshadow other goals); Richard G. Newell, *The Role of Energy Technology Policy Alongside Carbon Pricing*, *in* IMPLEMENTING A US CARBON TAX: CHALLENGES AND DEBATES 178, 188 (Ian Parry et al. eds., 2015).

[7] Georgios Tziralis & Ilias Tatsiopoulos, *Prediction Markets: An Extended Literature Review*, 1 J. PREDICTION MKTS., no.1, 2007, at 75, 75 (2007). For reviews of the academic literature on prediction markets, see generally *id.* and Christian F. Horn et al., *Prediction Markets - A Literature Review 2014 Following Tziralis and Tatsiopoulos*, 8 J. PREDICTION MKTS., no.2, 2014, at 89, 89.

[8] *See generally* Joyce E. Berg & Thomas A. Rietz, *Prediction Markets as Decision Support Systems*, 5 INFO. SYS. FRONTIERS 79 (2003) (detailing how prediction markets use information to make predictions in a variety of contexts, including the 1996 presidential election).

[9] Since the contract pays $1 if Elizabeth Warren wins, then a price of $0.55 implies that the market gives Warren a fifty-five percent chance of winning if she is the Democratic nominee. *See* Justin Wolfers & Eric Zitzewitz, *Interpreting Prediction Market Prices as Probabilities* 8-12 (Inst. for Study of Labor (IZA) Discussion Papers,

We propose that policymakers sponsor similar markets for predicting the success of climate policies conditioned on the adoption of those policies. The government could, for example, use prediction markets to forecast whether subsidizing research to develop a more efficient gasoline engine would reduce carbon emissions in the transportation sector. The market operator could issue a prediction market contract that would pay $1 for each 100 million metric tons of carbon emissions from the transportation sector in the year 2030. If such a contract were selling for $20, its price would imply a forecast of two billion metric tons. One version of the contract would be conditioned on the government funding gasoline engine research and another on the government not funding the research. The difference in price would forecast the effect of the subsidy.

Prediction markets have been shown to outperform other forecasting mechanisms in a wide range of contexts — from predicting election outcomes and economic trends to guessing Oscar winners.[10] Against this background, recent scholarship argues that prediction markets could predict future temperature levels and help resolve the debate over whether global warming is really a problem.[11] Going one step further, this Article explores the potential of conditional prediction markets to forecast the effectiveness of competing climate policy proposals and to assist policymakers with their selection, design, and implementation.[12]

no. 2092, 2006) (Ger.).

10 *See infra* Part I.C.2.

11 *See* Shi-Ling Hsu, *A Prediction Market for Climate Outcomes*, 83 U. COLO. L. REV. 179, 205-06 (2011); Shi-Ling Hsu, *Climate Change Regulation and Prediction Markets*, REG., Summer 2014, at 36-37 (2014); Michael P. Vandenbergh et al., *Energy and Climate Change: A Climate Prediction Market*, 61 UCLA L. REV. 1962, 1966 (2014); *see also* Elmira Aliakbari & Ross McKitrick, Information Aggregation in a Prediction Market for Climate Outcomes 29-30 (Feb. 3, 2017) (unpublished manuscript) (on file with the University of Guelph) (Can.). Another recent paper explores whether prediction markets might generate a consensus on the factors that cause climate change. John J. Nay et al., *Betting and Belief: Prediction Markets and Attribution of Climate Change*, *in* IEEE PROCEEDINGS OF THE 2016 WINTER SIMULATION CONFERENCE 1666, 1666 (T.M.K. Roeder et al. eds., 2016).

12 The work closest to our own is an article by Scott Sumner and Aaron Jackson in which they proposed a set of prediction markets designed to forecast global temperature and greenhouse gas levels, and they briefly discussed in general terms how those markets might assist policymakers and help shape policy. Scott Sumner & Aaron L. Jackson, Using Prediction Markets to Guide Global Warming Policy §§ 4-5 (Dec. 9, 2008) (unpublished manuscript), http://www.econmodels.com/upload7282/efae68d98251d757b48dfaef0295c28e.pdf. Similarly, Sebastian Goers and his colleagues have suggested that prediction markets might help policymakers predict if and when certain environmentally friendly technologies will be invented. Sebastian R.

Part I makes the case that prediction markets have the potential to significantly improve upon the decision-making procedures of traditional legal institutions. Drawing on the literature on government failure, we examine specific reasons why policymakers and regulators sometimes act contrary to the public interest, including information deficits, cognitive and emotional biases, and special interest influence. We also survey existing mechanisms for addressing these problems, such as cost-benefit analysis and expert deliberation, and discuss their limitations. We then lay out the potential of prediction markets to improve government decision making through more reliable and transparent forecasts that aggregate widely dispersed information in an unbiased way untainted by interest group politics.

Part II argues that the government should use prediction markets to better allocate green subsidies to promote clean technology innovation. In the short term, we advocate for incremental changes to the process by which grant-making agencies fund clean-technology research. The Department of Energy's Advanced Research Project Agency-Energy program ("ARPA-E"), for example, could immediately incorporate prediction markets into its project-funding decisions without the need for congressional action. Smaller-scale experimentation with prediction markets by ARPA-E would allow for the development of an empirical track record of prediction market performance in federal agencies. Once prediction markets prove themselves, more radical reforms could include the use of these markets by Congress in allocating larger sums of money.

Moving from the federal to the state level, Part III discusses ways in which states could incorporate prediction markets to improve their climate and energy policies. Without a coherent federal policy strategy to address climate change and promote clean energy, states have emerged as key drivers of climate change mitigation and clean energy innovation.[13] With a veritable potpourri of policies in place, states are

Goers et al., *New and Old Market-Based Instruments for Climate Change Policy*, 12 ENVTL. ECON. & POL'Y STUD. 1, 23-26 (2010).

[13] Felix Mormann, *Clean Energy Federalism*, 67 FLA. L. REV. 1621, 1625-26, 1629-30 (2015) [hereinafter *Clean Energy Federalism*] (exploring the ideal institutional level of implementation for select climate and clean energy policies); Felix Mormann, *Constitutional Challenges and Regulatory Opportunities for State Climate Policy Innovation*, 41 HARV. ENVTL. L. REV. 189, 190-91 (2017) [hereinafter *Constitutional Challenges*] (discussing constitutional limitations on the freedom of states to adopt effective climate and clean energy policies). For an overview of state climate policy actions, see Kirsten H. Engel & Barak Y. Orbach, *Micro-Motives and State and Local Climate Change Initiatives*, 2 HARV. L. & POL'Y REV. 119, 123-24 (2008); Daniel A. Farber, *Climate Change, Federalism, and the Constitution*, 50 ARIZ. L. REV. 879, 883-92

living up to the Brandeisian ideal of "laboratories of democracy."[14] But which policies best tackle the daunting challenges presented by climate change? Prediction markets have the potential to shed light on this critical question as well as increase the benefits and reduce the risks inherent in state climate policy experimentation.

I. HOW TRADITIONAL LEGAL INSTITUTIONS CAN BENEFIT FROM PREDICTION MARKETS

This Part discusses reasons why policymakers may sometimes adopt ineffective or inefficient policies and explains some of the problems that plague existing legal institutions. We then discuss the potential for prediction markets to address these problems.

A. Why Legislatures Sometimes Adopt Bad Laws

Voters likely have at least some influence over public policy.[15] As a result, understanding legislative decision making starts with understanding voter behavior. The notion that politicians respond to voters' policy preferences may seem like welcome news in a democracy. The ideal of democratically legitimized policy choices, however, ignores the reality that many voters are woefully ignorant about politics and policy.[16] Moreover, voters often suffer from cognitive and emotional biases that lead them to support or oppose particular policies even though they might not do so if they were fully informed and unbiased.[17]

That voters' policy preferences are often biased and uninformed should come as no surprise. Public policy is complex, a single vote is rarely decisive,[18] and most of the consequences of bad policies fall on

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(2008); Richard B. Stewart, *States and Cities as Actors in Global Climate Regulation: Unitary vs. Plural Architectures*, 50 ARIZ. L. REV. 681, 683-88 (2008).

[14] *See* New State Ice Co. v. Liebmann, 285 U.S. 262, 311 (1932) (Brandeis, J., dissenting).

[15] *See* JAMES A. STIMSON, TIDES OF CONSENT: HOW PUBLIC OPINION SHAPES AMERICAN POLITICS xvi (2004); Paul Burstein, *The Impact of Public Opinion on Public Policy: A Review and an Agenda*, 56 POL. RES. Q. 29, 36 (2003); Brandice Canes-Wrone et al., *Out of Step, Out of Office: Electoral Accountability and House Members' Voting*, 96 AM. POL. SCI. REV. 127, 138 (2002).

[16] *See* MICHAEL X. DELLI CARPINI & SCOTT KEETER, WHAT AMERICANS KNOW ABOUT POLITICS AND WHY IT MATTERS 62-104 (1996); ILYA SOMIN, DEMOCRACY AND POLITICAL IGNORANCE: WHY SMALLER GOVERNMENT IS SMARTER 17-61 (2013).

[17] For a review of the literature on voter biases, see generally Gary M. Lucas, Jr., & Slavisa Tasic, *Behavioral Public Choice and the Law*, 118 W. VA. L. REV. 199 (2015).

[18] DENNIS C. MUELLER, PUBLIC CHOICE III 304-05 (2003); *see also* Jonathan R.

others.[19] As a result, individual voters have little incentive to seek out all relevant information. Moreover, unbiased thinking requires significant effort and our minds are usually lazy.[20] When people are uninformed and lack motivation, they often analyze complex problems superficially by invoking simple cues and decision heuristics that can result in errors.[21] For example, voters sometimes invoke the availability heuristic — a tendency to estimate the importance and frequency of an event based upon how easy it is to recall examples of it — leading them to prioritize threats that are familiar, salient, and accompanied by vivid news images (e.g., terrorism), over those that are not (e.g., climate change).[22]

When it comes to climate policy, the public's views on particular policy instruments often contradict expert opinion in ways that are hard to explain without resorting to psychology. For instance, voters strongly support command-and-control regulations and green subsidies, which many economists condemn as inefficient, yet voters steadfastly oppose a carbon tax, which experts maintain would reduce carbon emissions at a much lower cost.[23] One possible explanation for the difference between expert and voter opinion is that voters engage in a sort of intuitive cost-benefit analysis that is biased against a carbon tax because, relative to alternative policies, the costs of the tax are more salient while the benefits are less so.[24]

While voter bias and ignorance present significant hurdles to effective climate policy, politicians probably have some slack to ignore voters' wishes and implement their own agenda. Perhaps voters simply fail to pay attention or they are subject to partisan bias and dutifully support the politicians currently in control of their favored party even if this means modifying their own policy views.[25] In theory, politicians

Macey, *Public Choice: The Theory of the Firm and the Theory of Market Exchange*, 74 CORNELL L. REV. 43, 46-51 (1988) (discussing the groups likely to drive legislation). For an assessment of conventional public choice narrative in an environmental policy context, see Richard L. Revesz, *Federalism and Environmental Regulation: A Public Choice Analysis*, 115 HARV. L. REV. 553, 559-71 (2001).

19 *See* Bryan Caplan, *Majorities Against Utility: Implications of the Failure of the Miracle of Aggregation*, 26 SOC. PHIL. & POL'Y 198, 207-08 (2008).

20 *See* DANIEL KAHNEMAN, THINKING, FAST AND SLOW 39-49 (2011).

21 *See* THOMAS GILOVICH ET AL., SOCIAL PSYCHOLOGY 281-86 (3d ed. 2013).

22 Cass R, Sunstein, *The Availability Heuristic, Intuitive Cost-Benefit Analysis, and Climate Change*, 77 CLIMATIC CHANGE 195, 200-03 (2006).

23 Gary M. Lucas, Jr., *Voter Psychology and the Carbon Tax*, 90 TEMP. L. REV. 1, 11-13 (2017).

24 *Id.* at 22.

25 *See* CHRISTOPHER H. ACHEN & LARRY M. BARTELS, DEMOCRACY FOR REALISTS: WHY

could use the slack that they possess to promote the public interest, correcting for voter biases. Unfortunately, politicians may be self-interested,[26] beholden to special interest groups,[27] hampered by a lack of information and policy expertise,[28] and subject to the same biases that plague voters.[29]

Not surprisingly then, it is easy to identify climate and environmental legislation that is inefficient and, in some cases, even counterproductive.[30] For example, subsidies for ethanol, which are backed by politicians and voters alike, have cost billions of tax dollars while producing little, if any, environmental benefit.[31] This and other examples of bad environmental legislation motivate the search for decision-making mechanisms that will improve public policy.

B. Why Administrative Agencies Make Mistakes

Given the problems with legislative decision making, delegating climate policy to administrative agencies seems appealing. Bureaucrats are arguably more insulated than legislators from public pressure and interest group lobbying, and their narrow jurisdictional focus allows them to develop greater technical expertise specific to their field.[32] Yet, there are many reasons why even agencies may make significant mistakes.

First, while bureaucrats have some slack to ignore the preferences of voters and politicians, politicians have various means for keeping agencies in line, including control over agency budgets and staffing

ELECTIONS DO NOT PRODUCE RESPONSIVE GOVERNMENT 309-10 (Tali Mendelberg ed., 2016).

[26] *See* James M. Buchanan & Gordon Tullock, *The Calculus of Consent: Logical Foundations of Constitutional Democracy*, *in* 3 THE COLLECTED WORKS OF JAMES BUCHANAN 1, 18-30 (1999).

[27] MUELLER, *supra* note 18, at 475-76, 489-90, 493-94 (analyzing the theory that interest groups affect legislators' votes).

[28] *See, e.g.*, BRUCE A. ACKERMAN & WILLIAM T. HASSLER, CLEAN COAL/DIRTY AIR: OR HOW THE CLEAN AIR ACT BECAME A MULTIBILLION-DOLLAR BAIL-OUT FOR HIGH-SULFUR COAL PRODUCERS AND WHAT SHOULD BE DONE ABOUT IT 26-29 (1981).

[29] Lucas & Tasic, *supra* note 17, at 214-15.

[30] *See, e.g.*, ACKERMAN & HASSLER, *supra* note 28, at 2; GRAETZ, *supra* note 6; NAT'L RESEARCH COUNCIL, EFFECTS OF U.S. TAX POLICY ON GREENHOUSE GAS EMISSIONS 3-7 (William Nordhaus et al. eds., 2013) [hereinafter TAX POLICY].

[31] Robert Hahn & Caroline Cecot, *The Benefits and Costs of Ethanol: An Evaluation of the Government's Analysis*, 35 J. REG. ECON. 275, 275-80, 283-285 (2009); *see* NAT'L RESEARCH COUNCIL, TAX POLICY, *supra* note 30, at 97-102.

[32] JOHN F. MANNING & MATTHEW C. STEPHENSON, LEGISLATION AND REGULATION 351-55 (2d ed. 2013) (reviewing the literature on this point).

decisions.[33] Consequently, agency decision making is not immune to the biases of voters and politicians or to political corruption.[34] Second, bureaucrats may themselves be captured by special interest groups.[35] The mechanisms of regulatory capture include "cultural capture," in which regulatory actions serve the ends of a special interest group because bureaucrats have come to identify members of that group as part of their own in-group and have formed close relationships with them, perhaps as a result of the revolving door between industry and government.[36] Third, some bureaucrats may be less concerned about the public interest than they are about career advancement and protecting their own jobs, salaries, and reputations, or about maximizing the power and budgets of the agencies for which they work.[37] Fourth, like voters and politicians, bureaucrats may suffer

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33 *Id.* at 406-544; *see* Elena Kagan, *Presidential Administration*, 114 HARV. L. REV. 2245, 2298 (2001); Matthew D. McCubbins et al., *Administrative Procedures as Instruments of Political Control*, 3 J.L. ECON. & ORG. 243, 246-47, 273-74 (1987); Matthew D. McCubbins et al., *Structure and Process, Politics and Policy: Administrative Arrangements and the Political Control of Agencies*, 75 VA. L. REV. 431, 440-44, 468-82 (1989).

34 *See* SOMIN, *supra* note 16, at 184 (arguing that voter ignorance and irrationality are "likely to reduce the quality of any delegations to experts that are enacted into law"). For examples of how political pressure has influenced agency decision making in the environmental context, see Robert R. Kuehn, *Bias in Environmental Agency Decision Making*, 45 ENVTL. L. 957, 959-61 (2015). For a famous case study demonstrating how political pressure undermined automobile safety regulation and encouraged an aggressive focus on recalling defective automobiles that likely contributed little to vehicle safety, see Jerry L. Mashaw, *Law and Engineering: In Search of the Law-Science Problem*, 66 LAW & CONTEMP. PROBS. 135, 141-44 (2003); *see also* Jerry L. Mashaw & David L. Harfst, *Inside the National Highway Traffic Safety Administration: Legal Determinants of Bureaucratic Organization and Performance*, 57 U. CHI. L. REV. 443, 465, 478-79 (1990). For a discussion of how industry threats might persuade bureaucrats to act against the public interest, see Sanford C. Gordon & Catherine Hafer, *Flexing Muscle: Corporate Political Expenditures as Signals to the Bureaucracy*, 99 AM. POL. SCI. REV. 245, 258 (2005). A related concern arises if bureaucrats know that their mistakes will come to light if they harm an industry group, but not if they harm the public interest. *See* Clare Leaver, *Bureaucratic Minimal Squawk Behavior: Theory and Evidence from Regulatory Agencies*, 99 AM. ECON. REV. 572, 573-74 (2009).

35 For a compilation of recent contributions to the regulatory capture literature, see generally PREVENTING REGULATORY CAPTURE: SPECIAL INTEREST INFLUENCE AND HOW TO LIMIT IT (Daniel Carpenter & David A. Moss eds., 2014) [hereinafter PREVENTING REGULATORY CAPTURE]. For examples of regulatory capture in the environmental context, see Kuehn, *supra* note 34, at 958-60.

36 James Kwak, *Cultural Capture and the Financial Crisis*, *in* PREVENTING REGULATORY CAPTURE *supra* note 35, at 71, 79-98.

37 For a discussion of several models of bureaucratic behavior, see MUELLER, *supra* note 18, at 359-85.

from cognitive and emotional biases, including ideological bias, overconfidence in their ability to create welfare-improving regulations, and tunnel vision, or the tendency to focus excessively on their agency's narrowly defined mission while ignoring competing concerns.[38] Finally, when relevant information is broadly dispersed, individual bureaucrats may not know enough to decide wisely. A notorious example of this phenomenon was the consistent failure of central planners in the Soviet Union to properly allocate goods and resources due to lack of information about what was needed when and where.[39]

While these problems with agency decision making are troubling and potentially significant, various administrative procedures seek to address them. The notice-and-comment rulemaking process[40] and centralized review of agency rules by the Office of Information and Regulatory Affairs[41] aim to promote transparency and accountability, help agencies gather dispersed information, and counteract biases such as tunnel vision. As a last resort, courts can strike down regulations that they deem arbitrary.[42] While helpful, these procedural safeguards are no panacea.[43]

Four mechanisms designed to promote better bureaucratic decisions are worth discussing in detail. As we will show, group deliberation, peer review, cost-benefit analysis, and expert surveys can help policymakers, but also introduce significant concerns of their own. As a result, these decision-making mechanisms can potentially be replaced or improved upon by prediction markets.

As with prediction markets, the goal of group deliberation is to aggregate dispersed information as well as mitigate individual biases. The literature on group decision making, however, shows that deliberating groups suffer from four major flaws.[44] First, they often amplify the biases and errors of individual group members. Second,

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38 Lucas & Tasic, *supra* note 17, at 252-57.

39 *See* Richard E. Ericson, *The Classical Soviet-Type Economy: Nature of the System and Implications for Reform*, 5 J. ECON. PERSP. 11, 15-25 (1991).

40 5 U.S.C. § 553 (2018).

41 For a discussion of how the Office of Information and Regulatory Affairs operates, see generally CASS R. SUNSTEIN, VALUING LIFE: HUMANIZING THE REGULATORY STATE 11-46 (2014).

42 5 U.S.C. § 706(2) (2018).

43 *See, e.g.*, Nicholas Bagley & Richard L. Revesz, *Centralized Oversight of the Regulatory State*, 106 COLUM. L. REV. 1260, 1263-1311 (2006); Stephen J. Choi & A.C. Pritchard, *Behavioral Economics and the SEC*, 56 STAN. L. REV. 1, 36-40 (2003).

44 CASS R. SUNSTEIN, INFOTOPIA: HOW MANY MINDS PRODUCE KNOWLEDGE 75 (2006) [hereinafter INFOTOPIA].

they frequently fail to elicit all relevant information from members, giving too much weight to information possessed by all members and too little weight to information known to only a few. Third, they are prone to informational and reputational cascades whereby group members conceal their doubts (and the information prompting them) about the group's decision out of deference to the majority or for fear of reputational harm. Finally, they often produce group polarization, which occurs when group members initially lean in a particular direction (e.g., favoring the death penalty) and deliberation pushes them further in that direction because arguments favoring that position are more likely to be mentioned and social pressure yields conformity. As a result, deliberating groups are especially likely to make bad decisions when a large proportion of group members are biased, important information is known to only a few members who remain silent, and the group is highly cohesive so that members feel intense pressure to conform and to reject the views of outsiders.[45]

Peer review is a procedure frequently employed by government agencies in the selection process for research grants. Despite peer review's status among scientists as a venerable institution, evidence of its effectiveness is mixed. On one hand, a recent study of grants made by the National Institutes of Health found a "one-standard deviation worse peer-review score among awarded grants [to be] associated with 15% fewer citations, 7% fewer publications, 19% fewer high-impact publications, and 14% fewer follow-on patents," even after controlling for various characteristics of the grant recipient.[46] These numbers suggest that peer review can help effectively allocate grant money to those researchers whose work will have the greatest impact. On the other hand, another recent study found evidence of significant bias in peer review and in particular that "evaluators systematically give lower scores to research proposals that are closer to their own areas of expertise and to those that are highly novel."[47] Beyond the grant selection process, numerous scholars have documented problems with peer review as part of the article selection process for academic

[45] *Id.* at 75-102.

[46] Danielle Li & Leila Agha, *Big Names or Big Ideas: Do Peer-Review Panels Select the Best Science Proposals?*, 348 SCI. 434, 434 (2015).

[47] Kevin J. Boudreau et al., *Looking Across and Looking Beyond the Knowledge Frontier: Intellectual Distance, Novelty, and Resource Allocation in Science*, 62 MGMT. SCI. 2765, 2765 (2016); *see also* Thomas O. McGarity, *Peer Review in Awarding Federal Grants in the Arts and Sciences*, 9 HIGH TECH. L.J. 1, 38-55 (1994) (discussing possible biases in the peer review process).

journals.[48] The primary lesson of this literature is that peer review likely has some value, but also suffers from significant drawbacks, particularly when it comes to evaluating highly innovative ideas.

Cost-benefit analysis ("CBA") is a well-established feature of agency decision making and is generally required for any significant regulatory action at the federal level.[49] CBA can facilitate transparency and accountability[50] as well as correct various biases (cognitive or otherwise) by forcing bureaucrats to carefully consider the likely consequences of proposed regulations.[51] Nevertheless, CBA is controversial in part because it requires estimating future costs and benefits that may be very difficult to forecast.[52] Moreover, the government often fails to conduct CBA properly in compliance with guidelines suggested by regulatory experts or the Office of Management and Budget.[53]

Finally, expert surveys seek to leverage the knowledge and experience of the brightest minds in a given field. The problem with expert surveys, however, is that experts may be unreliable, particularly given their lack of incentive for accuracy. When it comes to forecasting, experts often make poor predictions.[54] Moreover, experts may be corrupt or perceived as such,[55] tell people what they want to

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[48] *E.g.*, DAVID SHATZ, PEER REVIEW: A CRITICAL INQUIRY 35-108 (2004); Juan Miguel Campanario, *Peer Review for Journals as It Stands Today: Part 1*, 19 SCI. COMM. 181, 191-203 (1998); Juan Miguel Campanario, *Peer Review for Journals as It Stands Today: Part 2*, 19 SCI. COMM. 277, 280-82 (1998); Peter M. Rothwell & Christopher N. Martyn, *Reproducibility of Peer Review in Clinical Neuroscience: Is Agreement Between Reviewers Any Greater than Would Be Expected by Chance Alone?*, 123 BRAIN 1964, 1966-68 (2000).

[49] For a discussion of this requirement, see MANNING & STEPHENSON, *supra* note 32, at 513-32.

[50] *See* Eric A. Posner, *Controlling Agencies with Cost-Benefit Analysis: A Positive Political Theory Perspective*, 68 U. CHI. L. REV. 1137, 1140-41 (2001).

[51] *See generally* Cass R. Sunstein, *Cognition and Cost-Benefit Analysis*, 29 J. LEGAL STUD. 1059 (2000).

[52] *See* Amy Sinden, *Cost-Benefit Analysis*, *in* DECISION MAKING IN ENVIRONMENTAL LAW 295, 304-05 (LeRoy C. Paddock et al. eds., 2016).

[53] Robert W. Hahn, *An Evaluation of Government Efforts to Improve Regulatory Decision Making*, 3 INT'L REV. ENVTL. & RESOURCE ECON. 245, 258-59 (2009).

[54] *See* PHILIP E. TETLOCK, EXPERT POLITICAL JUDGMENT: HOW GOOD IS IT? HOW CAN WE KNOW? 25-66 (2005) (presenting substantial evidence that dilettantes and simple algorithms often beat expert forecasts).

[55] *See, e.g.*, Robin Cooper Feldman et al., *Open Letter on Ethical Norms in Intellectual Property Scholarship*, 29 HARV. J.L. & TECH. 339, 340 (2016); Eric Lipton et al., *Think Tank Scholar or Corporate Consultant? It Depends on the Day*, N.Y. TIMES (Aug. 8, 2016), https://www.nytimes.com/2016/08/09/us/politics/think-tank-scholars-corporate-consultants.html; Brody Mullins & Jack Nicas, *Paying Professors: Inside*

hear even if it is not true,[56] herd with other experts to protect their professional reputations,[57] and fall victim to the subtle biases present within their field.[58]

C. *Prediction Markets: A Catalyst for Better Legislative and Agency Decision Making*

This section argues that prediction markets have the potential to improve climate policy by addressing some of the problems with existing legal institutions and processes outlined above. We begin by surveying the theory and evidence that prediction markets improve on other forecasting techniques. We then explain features beyond mere forecast accuracy that should make prediction markets attractive to policymakers.

1. More Accurate Forecasts: Theory

Economists have long recognized the power of prices to convey information.[59] As applied to prediction markets, rational expectations theory[60] and the strong form of the efficient markets hypothesis[61] imply that prediction markets accurately forecast future events because the marginal trader in the market has unbiased expectations and market prices incorporate all relevant information, making it

Google's Academic Influence Campaign, WALL ST. J. (July 14, 2017, 9:14 AM ET), https://www.wsj.com/articles/paying-professors-inside-googles-academic-influence-campaign-1499785286.

56 *See* Canice Prendergast, *A Theory of "Yes Men*,*"* 83 AM. ECON. REV. 757, 757-59 (1993).

57 *See* David S. Scharfstein & Jeremy C. Stein, *Herd Behavior and Investment*, 80 AM. ECON. REV. 465, 465-67 (1990).

58 *See, e.g.*, Robyn M. Dawes et al., *Clinical Versus Actuarial Judgment*, 243 SCI. 1668, 1671-73 (1989) (discussing biases to which psychologists are subject); Lee Jussim et al., *Ideological Bias in Social Psychological Research*, *in* SOCIAL PSYCHOLOGY AND POLITICS 91, 98-105 (Joseph P. Forgas et al. eds., 2015) (presenting evidence of ideological bias in social psychology); Luigi Zingales, *Preventing Economists' Capture*, *in* PREVENTING REGULATORY CAPTURE, *supra* note 35, at 124, 130-44 (providing evidence of bias among economists and discussing the mechanisms contributing to it).

59 *See, e.g.*, F.A. Hayek, *The Use of Knowledge in Society*, 1 N.Y.U. J.L. & LIBERTY 5, 12-13 (2005) (This article was originally published by *The American Economic Review* in 1945.).

60 *See generally* SANFORD J. GROSSMAN, THE INFORMATIONAL ROLE OF PRICES 11-40 (1989); STEVEN M. SHEFFRIN, RATIONAL EXPECTATIONS (2d ed. 1996).

61 *See generally* Eugene F. Fama, *Efficient Capital Markets II*, 46 J. FIN. 1575, 1577, 1603-08 (1991); Eugene F. Fama, *Efficient Capital Markets: A Review of Theory and Empirical Work*, 25 J. FIN. 383, 409-13 (1970).

impossible to improve upon the predictions implied by those prices.[62] Even if real-world prediction markets are less than perfectly efficient,[63] there are reasons to believe that they will often outperform other forecasting techniques, including forecasting by means of expert surveys or group deliberation.

First, prediction markets that are open to a large group of traders aggregate information that is widely dispersed.[64] Such "markets provide a centralized locus for information aggregation" so that anyone with relevant information knows where to go to disclose it and how.[65] Moreover, "the market provides an algorithm for aggregating opinions."[66] Unlike group deliberation, which often adheres to the "principle of 'one person, one vote,'" prediction markets allow traders to register their confidence in their views by increasing the amount wagered.[67] In addition, anyone with relevant information can participate regardless of social or professional status.[68] Relatedly, if the

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62 *See* John O. Ledyard, *Designing Information Markets for Policy Analysis*, *in* INFORMATION MARKETS: A NEW WAY OF MAKING DECISIONS 37, 41-42 (Robert W. Hahn & Paul C. Tetlock eds., 2006); Justin Wolfers & Eric Zitzewitz, *Prediction Markets*, 18 J. ECON. PERSP., Spring 2004, at 107, 108 [hereinafter *Prediction Markets*].

63 The stock market provides evidence that speculative markets can be efficient. *See generally* Mark Rubinstein, *Rational Markets: Yes or No? The Affirmative Case*, 57 FIN. ANALYSTS J., May-June 2001, at 15 (presenting evidence that index funds, which are speculative in nature, consistently outperform actively managed mutual funds). Moreover, "betting markets have offered support in favor of the efficient markets hypothesis, especially in the market for all games in a given sport over a long time horizon." Rodney J. Paul & Andrew P. Weinbach, *Uses of Sports Wagering-Based Prediction Markets Outside of the World of Gambling*, *in* PREDICTION MARKETS: THEORY AND APPLICATIONS 157, 157 (Leighton Vaughan Williams ed., 2011); *cf.* Anastasios Oikonomidis & Johnnie Johnson, *Who Can Beat the Odds? The Case of Football Betting Reviewed*, *in* PREDICTION MARKETS: THEORY AND APPLICATIONS, *supra*, at 204, 206-08, 217 (reviewing the literature on the efficiency of soccer betting markets and concluding that "even though opportunities for profit theoretically exist, only the fastest, most efficient and highly determined players are likely to convert theory to practice and benefit from inefficient pricing in the football betting market"). For evidence that prediction markets are not perfectly efficient, see Joyce E. Berg & Thomas A. Rietz, Longshots, Overconfidence and Efficiency on the Iowa Electronic Market 17-27 (Sept. 2017) (unpublished manuscript), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1645062. For similar evidence related to experimental prediction markets, see Charles Noussair, *Experimental Prediction and Pari-Mutuel Betting Markets*, *in* PREDICTION MARKETS: THEORY AND APPLICATIONS, *supra*, at 174, 180-82.

64 *See* Wolfers & Zitzewitz, *Prediction Markets*, *supra* note 62, at 121.

65 M. Todd Henderson et al., *Predicting Crime*, 52 ARIZ. L. REV. 15, 23-24 (2010).

66 Wolfers & Zitzewitz, *Prediction Markets*, *supra* note 62, at 121 (emphasis omitted).

67 SUNSTEIN, INFOTOPIA, *supra* note 44, at 130-31.

68 Henderson et al., *supra* note 65, at 21.

opinions of traders are sufficiently diverse, prediction markets can take advantage of the wisdom of crowds, a phenomenon whereby forecasting errors by individuals tend to cancel each other out in the aggregate so that the resulting group forecast is more accurate than individual forecasts.[69]

Second, in contrast to group deliberation, prediction markets create an incentive for people to reveal policy-relevant information that they might otherwise fail to disclose.[70] Specifically, traders who have information suggesting that the market price is wrong can profit by trading on that information, thereby moving the market toward the efficient price.[71]

Third, prediction markets create an incentive for more and better research because traders with better information have an advantage in the market.[72] When expert forecasts disagree with the market price, experts can either bet on their models or revisit their assumptions to try to ascertain the source of the disagreement.[73]

Fourth, relative to other forecasting mechanisms, prediction markets may better evaluate information and more quickly incorporate new data.[74] As mentioned above, traders who are more certain about the quality of their information can register their conviction by betting more money.[75] Conversely, traders who are wrong lose money, so uninformed people have an incentive to stay out of the market. This feature distinguishes prediction markets from group deliberation, a setting in which talk is cheap and participants are not forced to put their money where their mouths are.

Finally, prediction markets create incentives to avoid biases in forecasting, whether cognitive, emotional, reputational, or financial. A strong body of evidence suggests that better incentives can reduce bias, especially cognitive and emotional bias, and improve decision

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[69] For a review of the literature on the wisdom of crowds, see Joseph P. Simmons et al., *Intuitive Biases in Choice Versus Estimation: Implications for the Wisdom of Crowds*, 38 J. CONSUMER RES. 1, 1-2 (2011). The authors note that under the wisdom of crowds theory a crowd's judgment is most likely to be accurate "when the crowds' judges are (1) knowledgeable, (2) motivated to be accurate, (3) independent, and (4) diverse." *Id.* at 2.

[70] *See* Wolfers & Zitzewitz, *Prediction Markets*, *supra* note 62, at 121.

[71] For evidence that prediction markets are generally efficient in the sense of allowing few opportunities for arbitrage, see *id.* at 116-19.

[72] *Id.* at 121.

[73] Henderson et al., *supra* note 65, at 24.

[74] *See* Oleg Bondarenko & Peter Bossaerts, *Expectations and Learning in Iowa*, 24 J. BANKING & FIN. 1535, 1545-50 (2000).

[75] Henderson et al., *supra* note 65, at 23.

making.[76] With their promise of monetary reward, prediction markets provide strong incentives for unbiased forecasting. Similarly, the ability of traders to participate anonymously in prediction markets eliminates the risk of reputational damage that comes with sharing information as part of a deliberating group.[77] Importantly, a prediction market can function well even if many traders within the market are biased, as long as the marginal trader — the one who sets the market clearing price — is not.[78]

2. More Accurate Forecasts: Empirical Evidence

As compelling as the theoretical case for prediction markets is, the primary reason to believe that they can be useful to policymakers is their strong track record of forecast accuracy. Over several decades and across various domains, speculative markets, including prediction markets, have fared well relative to expert predictions and other forecasting mechanisms. Moreover, unlike algorithms, which are often highly specific to a given field, prediction markets are versatile enough to deliver forecasts in a variety of policy-relevant contexts.

To illustrate, consider the following summary of the empirical evidence. Prediction markets generally outperform polls in predicting election outcomes.[79] Horse race bettors beat horse race experts.[80] Economic derivatives markets beat the average forecast of a panel of

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76 *See, e.g.*, Bruno S. Frey & Reiner Eichenberger, *Economic Incentives Transform Psychological Anomalies*, 23 J. ECON. BEHAV. & ORG. 215, 225-26, 229-30 (1994) (explaining that the frequency and magnitude of bias or irrational behavior lessen when incentives are introduced); Erik Hoelzl & Aldo Rustichini, *Overconfident: Do You Put Your Money on It?*, 115 ECON. J. 305, 315-17 (2005) (summarizing results suggesting subjects' overconfidence bias may be reduced when money is at stake); Jonathan Klick & Gregory Mitchell, *Government Regulation of Irrationality: Moral and Cognitive Hazards*, 90 MINN. L. REV. 1620, 1633-36 (2006) (discussing incentives' "role in the quality of judgment and choice"); *cf.* Colin F. Camerer & Robin M. Hogarth, *The Effects of Financial Incentives in Experiments: A Review and Capital-Labor-Production Framework*, 19 J. RISK & UNCERTAINTY 7, 34-36 (1999) (explaining that sometimes incentives improve performance but often they do not).

77 SUNSTEIN, INFOTOPIA, *supra* note 44, at 104-05.

78 *See* Adam Mann, *Market Forecasts*, 538 NATURE 308, 310 (2016).

79 *E.g.*, Joyce E. Berg et al., *Prediction Market Accuracy in the Long Run*, 24 INT'L. J. FORECASTING 285, 286 (2008); Joyce Berg et al., *Results from a Dozen Years of Election Futures Markets Research*, *in* 1 HANDBOOK OF EXPERIMENTAL ECONOMICS RESULTS 742, 746-48 (Charles R. Plott & Vernon L. Smith eds., 2008) [hereinafter *Results*]; Wolfers & Zitzewitz, *Prediction Markets*, *supra* note 62, at 112.

80 *See* Stephen Figlewski, *Subjective Information and Market Efficiency in a Betting Market*, 87 J. POL. ECON. 75, 82-87 (1979).

experts in predicting economic outcomes.[81] Orange juice futures improve upon weather forecasts.[82] Stock prices identified the firm whose defective part caused the Challenger space shuttle crash well before the official investigation concluded.[83] Numerous companies have found that their internal prediction markets outperform expert forecasts in predicting product sales volume.[84] Furthermore, prediction markets have succeeded in forecasting the outcomes of sporting events,[85] movie box office receipts,[86] Oscar winners,[87] Google's market capitalization prior to its initial public offering,[88] a company's ability to meet project deadlines,[89] the reproducibility of published scientific research results,[90] and flu outbreaks.[91] Finally, in experiments designed to test their performance and limitations, "[t]he data give an encouraging, though qualified, picture of prediction

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81 *See* Refet S. Gürkaynak & Justin Wolfers, *Macroeconomic Derivatives: An Initial Analysis of Market-Based Macro Forecasts, Uncertainty, and Risk*, *in* NBER INTERNATIONAL SEMINAR ON MACROECONOMICS 2005, at 11, 15-20 (Jeffrey A. Frankel & Christopher A. Pissarides eds., 2007).

82 *See* Richard Roll, *Orange Juice and Weather*, 74 AM. ECON. REV. 861, 868-73 (1984).

83 Michael T. Maloney & J. Harold Mulherin, *The Complexity of Price Discovery in an Efficient Market: The Stock Market Reaction to the Challenger Crash*, 9 J. CORP. FIN. 453, 453, 473-74 (2003).

84 *E.g.*, Bo Cowgill & Eric Zitzewitz, *Corporate Prediction Markets: Evidence from Google, Ford, and Firm X*, 82 REV. ECON. STUD. 1309, 1310, 1337 (2015); Emile Servan-Schreiber, *Prediction Markets: Trading Uncertainty for Collective Wisdom*, *in* COLLECTIVE WISDOM: PRINCIPLES AND MECHANISMS 21, 29 (Hélène Landemore & Jon Elster eds., 2012); Charles R. Plott & Kay-Yut Chen, *Information Aggregation Mechanisms: Concept, Design and Implementation for a Sales Forecasting Problem* 13-14 (Cal. Inst. Tech. Soc. Sci., Working Paper No. 1131, 2002) (Hewlett-Packard). For a detailed review of the use of prediction markets by private firms, see DONALD N. THOMPSON, ORACLES: HOW PREDICTION MARKETS TURN EMPLOYEES INTO VISIONARIES 3-130 (2012).

85 *See, e.g.*, Emile Servan-Schreiber et al., *Prediction Markets: Does Money Matter?*, 14 ELECTRONIC MKTS. 243, 250 (2004).

86 *See, e.g.*, Wolfers & Zitzewitz, *Prediction Markets*, *supra* note 62, at 113-14.

87 *See, e.g.*, Deepak Pathak et al., *A Comparison of Forecasting Methods: Fundamentals, Polling, Prediction Markets, and Experts*, 9 J. PREDICTION MKTS., no. 2, 2015, at 1, 23-25.

88 *See* Joyce E. Berg et al., *Searching for Google's Value: Using Prediction Markets to Forecast Market Capitalization Prior to an Initial Public Offering*, 55 MGMT. SCI. 348, 349 (2009).

89 *See* SUNSTEIN, INFOTOPIA, *supra* note 44, at 116-17.

90 *See* Anna Dreber et al., *Using Prediction Markets to Estimate the Reproducibility of Scientific Research*, 112 PROC. NAT'L ACAD. SCI. U.S. 15343, 15343-45 (2015).

91 *See* Philip M. Polgreen et al., *Using Prediction Markets to Forecast Trends in Infectious Diseases*, 1 MICROBE 459, 463-64 (2006).

market performance" suggesting that prediction markets are "typically beneficial."[92]

While harnessing the full power of prediction markets likely requires allowing bets for real money, empirical evidence suggests that even markets based on play money or prizes can be remarkably accurate.[93] Private firms often use markets of this type to circumvent gambling restrictions, and many have found that the opportunity for bragging rights proves sufficient to motivate informed and unbiased trading.[94]

Notwithstanding this impressive empirical record, we readily acknowledge that prediction markets have limitations and do not function as a crystal ball. Specifically, they can prove inaccurate when traders, even in the aggregate, do not have all the relevant information needed to make an accurate prediction. This could be because the relevant information is unknown or hard to piece together, in which case, other prediction mechanisms are also likely to perform poorly. Another possibility is that a small group of people have a monopoly on valuable information relevant to the market, but either they are not trading or the potential that they might trade drives others out of the market.[95] This likely explains why prediction markets failed to predict that Iraq did not have weapons of mass destruction or that President Bush would appoint John Roberts to the Supreme Court.[96]

Yet, the fact that prediction markets sometimes fail to accurately predict an event does not mean that they are hopelessly flawed or useless. As a case in point, consider the high-profile failure of prediction markets to forecast Donald Trump's victory over Hillary Clinton in the 2016 presidential election. While it is true that the major prediction markets suggested that Trump had only between a

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[92] Noussair, *supra* note 63, at 185-86; *see also* Gerrit H. Van Bruggen et al., *Prediction Markets as Institutional Forecasting Support Systems*, 49 DECISION SUPPORT SYS. 404, 410-13 (2010) (presenting experimental evidence that prediction markets perform as well as or better than traditional forecasting mechanisms).

[93] *See e.g.*, THOMPSON, *supra* note 84, at 113, 115-16 (noting the "endowment effect" of play money); Sebastian Diemer & Joaquin Poblete, *Real-Money vs. Play-Money Forecasting Accuracy in Online Prediction Markets: Empirical Insights From iPredict*, 4 J. PREDICTION MKTS., no.3, 2010, at 21, 43; Servan-Schreiber et al., *supra* note 85, at 250.

[94] *See, e.g.*, THOMPSON, *supra* note 84, at 89-91 (noting that Google uses play money markets to avoid gambling restrictions); *see* Mann, *supra* note 78, at 310 (noting "several studies have shown that traders can be equally well motivated by the prestige of being right"); Servan-Schreiber et al., *supra* note 85, at 244-45.

[95] *See* Wolfers & Zitzewitz, *Prediction Markets*, *supra* note 62, at 121.

[96] SUNSTEIN, INFOTOPIA, *supra* note 44, at 134-36.

six percent and twenty-five percent chance of winning, it is also true that a small chance does not mean no chance. Moreover, Trump won by a thin margin. He lost the popular vote by nearly three million votes and narrowly won the electoral college thanks to razor-thin victories in Pennsylvania, Michigan, and Wisconsin.[97] Consequently, the popular notion that his victory was somehow inevitable is likely nothing more than hindsight bias. More importantly, in forecasting the election results, prediction markets generally did as well as or better than alternative approaches, including statistical poll aggregators.[98] All the evidence suggests that the outcome of the 2016 presidential election was very hard to predict. This raises an important point: even though prediction markets are imperfect, they can still be valuable as long as they perform well relative to other forecasting mechanisms.[99]

3. Other Benefits of Prediction Markets

In addition to improving forecasts, prediction markets possess other attractive features. First, they have the potential to provide policymakers with an easy-to-find, readily digestible, and highly reliable summary of complex information relevant to a particular policy, similar to the way in which stock prices summarize the value of firms.[100] Second, "markets provide instantaneous and continuous feedback to information providers through prices," ensuring that policymakers receive the most up-to-date information.[101] Third, prediction markets have the potential to promote more effective policymaking by increasing transparency and combating the perception that government forecasts are biased or influenced by special interest groups.[102] Moreover, if regulators choose to ignore

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97 FED. ELECTION COMM'N, OFFICIAL 2016 PRESIDENTIAL GENERAL ELECTION RESULTS 1-2, 6 (2017), https://transition.fec.gov/pubrec/fe2016/2016presgeresults.pdf; Philip Bump, *Donald Trump Will Be President Thanks to 80,000 People in Three States*, WASH. POST (Dec. 1, 2016), https://www.washingtonpost.com/news/the-fix/wp/2016/12/01/donald-trump-will-be-president-thanks-to-80000-people-in-three-states/.

98 *See* Lumenogic, *Did Donald Trump the Wisdom of Crowds?*, HYPERMIND GAZETTE (Nov. 14, 2016), https://blog.hypermind.com/2016/11/14/donald-trumps-the-wisdom-of-crowds/.

99 Robin Hanson, *Shall We Vote on Values, but Bet on Beliefs?*, 21 J. POL. PHIL. 151, 155-56 (2013) [hereinafter *Bet on Beliefs*].

100 Henderson et al., *supra* note 65, at 23-24.

101 *Id.* at 24.

102 *See* Michael Abramowicz, *Information Markets, Administrative Decisionmaking, and Predictive Cost-Benefit Analysis*, 71 U. CHI. L. REV. 933, 971 (2004) [hereinafter *Information Markets*]; Robert W. Hahn & Paul C. Tetlock, *Using Information Markets*

prediction market forecasts, the media, the public, and perhaps even the courts can hold them accountable by placing the burden on them to explain why.[103] Finally, prediction markets offer special appeal to conservatives who tend to be deeply distrustful of government forecasts and the policymaking process. Market-oriented conservatives may trust prediction market forecasts more than those issued by bureaucrats, academics, and other experts whom they often associate — justly or not — with the Democratic party.

II. PREDICTION MARKETS TO DIRECT GREEN SUBSIDIES

As we mentioned at the outset, most policy experts argue that seriously addressing climate change will require placing a price on carbon, and many advocate for a carbon tax.[104] If the government eventually adopts a carbon tax, the tax would yield considerable revenue, which raises the question of what to do with it. One option would be to use some substantial portion to fund green subsidies, including clean energy research and development. While a carbon tax remains widely unpopular, public support increases significantly when proposals stipulate that the government would use the resulting revenue to fund environmental programs.[105] In addition, several prominent economists have argued that the government may be able to drastically reduce the overall cost of climate change mitigation by making a large investment in clean technology that pushes the economy away from fossil fuels toward clean energy.[106] Remarkably, proposals for increased government spending to fund clean energy research have received support from climate and energy policy scholars across the political spectrum.[107] In sum, green subsidies have broad appeal among both experts and the public.

to Improve Public Decision Making, 29 HARV. J.L. & PUB. POL'Y 213, 263-64 (2005).

103 *Cf.* Henderson et al., *supra* note 65, at 42 ("One benefit of this transparency is that it would encourage political accountability — politicians who opt to ignore the market would likely have to build a strong case for their position.").

104 *See supra* note 1.

105 *See* Andrea Baranzini & Stefano Carattini, *Effectiveness, Earmarking, and Labeling: Testing the Acceptability of Carbon Taxes with Survey Data*, 19 ENVTL. ECON. & POL'Y STUD. 197, 211-13 (2017); Simon Dresner et al., *Social and Political Responses to Ecological Tax Reform in Europe: An Introduction to the Special Issue*, 34 ENERGY POL'Y 895, 900-01 (2006); Steffen Kallbekken & Marianne Aasen, *The Demand for Earmarking: Results from a Focus Group Study*, 69 ECOLOGICAL ECON. 2183, 2187 (2010).

106 *See, e.g.*, PHILIPPE AGHION ET AL., CTR. FOR CHANGE ECON. & POL'Y, PATH DEPENDENCE, INNOVATION, AND THE ECONOMICS OF CLIMATE CHANGE 7 (2014).

107 *See, e.g.*, STEVEN F. HAYWARD ET AL., POST-PARTISAN POWER: HOW A LIMITED AND

While green subsidies may sound good in theory, they could easily become a nightmare in practice. After all, the government has a mixed track record in choosing what technologies and activities to subsidize.[108] Special interest influence is a major concern in this context. Dieter Helm, for example, has argued that the European Union's climate policies have conferred large economic rents on special interests and have locked in investment in costly offshore wind at the expense of other, more promising renewables.[109]

Even when government is acting in good faith and in pursuit of the public interest, solutions are not always obvious. Simply investing in technologies that reduce emissions relative to the status quo may prove counterproductive. Zachary Liscow and Quentin Karpilow, for instance, have argued that fuel efficiency standards for automobiles, which many environmentalists support, "may perversely undermine climate efforts to the extent that they direct innovation away from zero-emission cars and toward improving the fuel efficiency of fossil-fuel vehicles."[110] Similarly, Philippe Aghion and his colleagues have suggested that policies designed to encourage the transition from coal to cleaner natural gas may reduce emissions in the short run, but they

DIRECT APPROACH TO ENERGY INNOVATION CAN DELIVER CLEAN, CHEAP ENERGY, ECONOMIC PRODUCTIVITY AND NATIONAL PROSPERITY 5-7 (2010); Jonathan H. Adler, *Eyes on a Climate Prize: Rewarding Energy Innovation to Achieve Climate Stabilization*, 35 HARV. ENVTL. L. REV. 1, 42-45 (2011); Robert W. Hahn, *Climate Policy: Separating Fact from Fantasy*, 33 HARV. ENVTL. L. REV. 557, 582-87 (2009) [hereinafter *Climate Policy*]; Mormann, *Renewables Revolution*, *supra* note 2, at 943-48.

[108] GRAETZ, *supra* note 6, at 187-95; NAT'L RESEARCH COUNCIL, PROSPECTIVE EVALUATION OF APPLIED ENERGY RESEARCH AND DEVELOPMENT AT DOE (PHASE TWO) 8 (2007); Linda R. Cohen & Roger G. Noll, *An Assessment of R&D Commercialization Programs*, *in* THE TECHNOLOGY PORK BARREL 365, 365-92 (Linda R. Cohen & Roger G. Noll eds., 1991); *see* JOHN A. ALIC ET AL., PEW CTR. ON GLOB. CLIMATE CHANGE, U.S. TECHNOLOGY AND INNOVATION POLICIES: LESSONS FOR CLIMATE CHANGE 11, 18-19 tbl.1 (2003) ("[W]here government has sought to define technical attributes or design features and 'pick winners' in the marketplace, failure has been a common outcome."); NAT'L RESEARCH COUNCIL, ENERGY RESEARCH AT DOE: WAS IT WORTH IT? ENERGY EFFICIENCY AND FOSSIL ENERGY RESEARCH 1978 TO 2000, at 6-8 (2001); NAT'L RESEARCH COUNCIL, TAX POLICY, *supra* note 30, at 98-99 (concluding that tax subsidies for ethanol have produced little if any environmental benefit); Richard G. Newell, *The Energy Innovation System: A Historical Perspective*, *in* ACCELERATING ENERGY INNOVATION: INSIGHTS FROM MULTIPLE SECTORS 25, 27-28 (Rebecca M. Henderson & Richard G. Newell eds., 2011).

[109] DIETER HELM, THE CARBON CRUNCH: HOW WE'RE GETTING CLIMATE CHANGE WRONG AND HOW TO FIX IT 94-99 (2012).

[110] Liscow & Karpilow, *supra* note 5, at 441.

may backfire in the long run by locking in long-lived natural gas infrastructure, which could impede the development of renewables.[111]

If Congress were to devote a large sum of money to clean technology innovation, the billion-dollar question would be who should determine how that money will be spent and according to what procedure. In this Part, we advocate for prediction markets as a key component of this process.

The risk of incompetence and the dangers of special interest influence lead many scholars to downplay the potential role for Congress in allocating funds and to instead call for substantial authority to be placed in the hands of administrative agencies advised by experts.[112] Congress could, for example, appropriate funds with a broad delegation of authority to one or more agencies instructing them to award grants to promote clean technology. In Section A, we explain how a grant-making institution could incorporate prediction markets to improve the grant selection process. In Section B, we discuss the more radical possibility of incorporating prediction markets at the congressional level. Section C addresses caveats and criticisms.

Based on the theory and evidence outlined in Part I, prediction markets are particularly useful when one or more of the following conditions are met: (i) relevant information is widely dispersed and those possessing it have little incentive (or perhaps even a disincentive) to voluntarily reveal it to policymakers; (ii) powerful groups have an incentive to spread misinformation; (iii) no single forecasting model dominates; (iv) true experts are hard to identify or may be subject to cognitive and emotional biases; (v) experts stand to benefit financially or reputationally from their forecasts; and (vi) policymakers will have difficulty correctly determining how much weight to give to particular pieces of information.

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111 AGHION ET AL., *supra* note 106, at 9-10. Natural gas-fired power plants are, however, a good match for the growing share of renewables in the U.S. and global electricity mix as their fast ramping capacity offers critical balancing services for intermittent power production from solar and wind generators.

112 *See, e.g.*, Adler, *supra* note 107, at 42-45 (advocating "technological inducement prizes for climate-related innovations" with Congress to "identify, in broad terms, the purposes for which prizes should be used," while delegating the task of developing specific prize proposals to expert panels overseen by agency administrators); Hahn, *Climate Policy*, *supra* note 107, at 587-88 (acknowledging the "clear danger" that climate R&D will become politicized and advocating for "giving respected agencies such as the National Science Foundation considerable funding authority, and encouraging or providing peer review").

All of these circumstances are present when it comes to predicting the consequences of green subsidies, which makes it difficult for policymakers to obtain reliable forecasts. Key technological breakthroughs could stem from a variety of sources that are not currently obvious even to elite scientists and engineers.[113] In other words, information is widely dispersed. Moreover, people with information may be reluctant to reveal it. For example, employees at a company developing novel carbon sequestration technology may conclude that the technology will never become commercially viable, but choose not to publicly reveal this belief for fear that their employer will retaliate against them. Special interest groups have an incentive to lobby for subsidies and even to procure and disseminate research that may be biased in their favor.[114] Experts may be biased due to ideological commitments and reputational concerns. Some climate scientists might be reluctant to discuss geoengineering for fear that policymakers and the public may conclude that an easy and painless solution to global warming will eventually present itself, offering a rationale for inaction in the meantime.[115] Others may be ideologically opposed to solutions that emphasize nuclear energy.[116] Even honest and unbiased experts may disagree about whether the government should, for example, focus its efforts on solar technology instead of wind, in which case policymakers may have no way to determine whom to believe. Prediction markets can help cut through the complexity and misinformation by giving a diverse group of people an incentive to truthfully and anonymously reveal what they know while producing a confidence-weighted price that summarizes relevant information.

A. *Use of Prediction Markets by ARPA-E and Other Administrative Agencies*

In this section, we use the Department of Energy's ARPA-E program as a case study to explain how an administrative agency might use prediction markets to improve the grant selection process.[117] ARPA-E

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113 *See* MCKINSEY & CO., "AND THE WINNER IS . . .": CAPTURING THE PROMISE OF PHILANTHROPIC PRIZES 23 (2009).

114 *See, e.g.*, Mullins & Nicas, *supra* note 55 (reporting on efforts by Google to fund academic research that allowed it to defend itself from antitrust regulation).

115 *See* Mark G. Lawrence, *The Geoengineering Dilemma: To Speak or Not to Speak*, 77 CLIMATIC CHANGE 245, 247 (2006).

116 *See* HELM, *supra* note 109, at 97; Hahn, *Climate Policy*, *supra* note 107, at 586.

117 We acknowledge that the government's prior experience with prediction markets has not been encouraging. In the early 2000s, the Defense Department

began operating in 2009 with a mission to promote transformative innovation in energy technology by funding high-risk, high-reward research that would not otherwise be funded by the private sector.[118] This mission includes the development of technologies to reduce carbon emissions.[119] Since its inception, ARPA-E has funded over $1.5 billion in research on more than 500 projects.[120] In 2010, for example, ARPA-E awarded $6 million to fund research related to energy kites — airborne wind turbines intended to generate and deliver wind power from an airborne platform.[121]

For our purposes, ARPA-E makes a nice case study because effective climate change mitigation requires new and transformative energy technologies. The prediction markets discussed in this section could, however, easily be adapted to fit the missions and procedures of other grant-making institutions and agencies.

1. The Grant Selection Process

To understand how ARPA-E might incorporate prediction markets, it is helpful to deconstruct the agency's existing process for granting awards. While the director of ARPA-E decides which projects ultimately receive funding, he makes this determination in close consultation with the agency's program directors.[122] In general, program directors are top researchers who typically serve three-year terms.[123] These elite scientists come from positions in industry, government, or academia, and usually return to one of these sectors following their stint with ARPA-E.[124]

sponsored a project to develop prediction markets to predict military and political stability around the world. The project was canceled for political reasons after certain politicians and the media (falsely) alleged that the government planned to encourage betting on terrorist attacks. Robin D. Hanson, *Designing Real Terrorism Futures*, 128 PUB. CHOICE 257, 258-63 (2006). We believe, however, that the prediction markets that we propose would be much less controversial because the subject matter is not as inflammatory.

118 42 U.S.C. § 16538(c)(1)-(2) (2018).

119 *Id.* § 16538(c)(1)(A)(ii).

120 Joseph S. Manser et al., *ARPA-E: Accelerating U.S. Energy Innovation*, 1 AM. CHEMICAL SOC'Y ENERGY LETTERS 987, 987 (2016).

121 ARPA-E, ARPA-E: THE FIRST SEVEN YEARS: A SAMPLING OF PROJECT OUTCOMES 83-84 (2016).

122 NAT'L ACADS. OF SCIS., ENG'G, AND MED., AN ASSESSMENT OF ARPA-E 38-39 (2017).

123 *See* William B. Bonvillian & Richard Van Atta, *ARPA-E and DARPA: Applying the DARPA Model to Energy Innovation*, 36 J. TECH. TRANSFER 469, 485-86 (2011).

124 NAT'L ACADS. OF SCIS., ENG'G, AND MED., *supra* note 122, at 56.

The ARPA-E funding process typically begins when a program director pitches an idea for a new program that targets an area of energy technology.[125] Once a program is accepted, agency staff gather information and solicit input from experts in the field to more precisely determine the research focus.[126] The process includes a "constructive confrontation," a debate about the program among all ARPA-E program directors.[127] If the agency's director approves the program, ARPA-E issues a funding opportunity announcement ("FOA") soliciting concept papers for research ideas pertaining to the program.[128]

Once concept papers are received, ARPA-E sends them to external reviewers who assign numerical scores.[129] "A merit review board, usually chaired by the program director who proposed the [program in the first place], reviews and discusses the . . . papers."[130] The board is not bound by the reviewers' scores, and instead makes independent recommendations to the ARPA-E director, who decides which applicants will be asked to submit full applications.[131] Full applications must include well-defined outcomes and deliverables as well as a project schedule that sets significant milestones.[132] The full applications then undergo another round of external reviews and review by a merit review board.[133] The ARPA-E director selects certain applications to negotiate the terms of an award, including the level of funding as well as specific and quantifiable project milestones.[134] Ultimately, the agency selects about five percent of the concept papers received for award negotiation.[135]

Projects typically receive funding for between six months and four years and award amounts average $2.3 million, with some projects receiving as much as $9.1 million.[136] Throughout the project, ARPA-E staff, including the program director, are in frequent contact with the

[125] *Id.* at 32.

[126] *Id.* at 34.

[127] *Id.*

[128] *Id.* ARPA-E also occasionally issues open-ended FOAs that request concept papers on any potentially transformative energy technology. *Id.* at 35-36.

[129] *Id.* at 37.

[130] *Id.*

[131] *Id.*

[132] *Id.* at 38-39; Manser et al., *supra* note 120, at 988.

[133] NAT'L ACADS. OF SCIS., ENG'G, AND MED., *supra* note 122, at 38-39.

[134] *Id.* at 40-42.

[135] *Id.* at 62. For review of projects that the agency has funded, see generally ARPA-E, *supra* note 121.

[136] NAT'L ACADS. OF SCIS., ENG'G, AND MED., *supra* note 122, at 68.

research team.[137] The program director periodically evaluates the project to determine if it is meeting milestones. If not, milestones may be modified, and, in some cases, funding for a project has been canceled because the program director concluded that the research team could not meet its objectives.[138]

2. Concerns with ARPA-E's Procedures

At Congress's request, the National Academy of the Sciences recently assessed the operations of ARPA-E. While the National Academy's report was largely positive, it also cautioned that it can take many years (perhaps even decades) to determine whether early-stage research of the type funded by ARPA-E will turn out to be transformative.[139] Consequently, empirical evidence to date is insufficient to draw reliable conclusions regarding the agency's success in achieving its mission.[140]

The National Academy's report notwithstanding, ARPA-E's procedures leave considerable room for improvement if the agency is to serve as a model for allocating the large and high-stakes research and development subsidies necessary to combat climate change. The program's funding decisions are controlled by a relatively small group of government officials who rely heavily on group deliberation and peer review. As we have discussed, these decision mechanisms, while potentially helpful, also suffer from serious flaws.[141] To their credit, officials at ARPA-E have taken measures to mitigate potential problems. ARPA-E is not bound by the scores that peer reviewers assign to applications, and the evidence suggests that the agency does not simply rubber stamp the applications that receive the highest scores.[142] In addition, ARPA-E encourages program directors to engage in constructive criticism when deliberating whether an application deserves funding.[143]

Nonetheless, we are not confident that these measures are sufficient to fully address the substantial problems with peer review and group deliberation. Moreover, they may introduce problems of their own. For example, the discretion ARPA-E gives to program directors may,

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137 *Id.* at 43.
138 *Id.*
139 *Id.* at 96.
140 *Id.* at 126.
141 *See supra* Part I.
142 *See* NAT'L ACADS. OF SCIS., ENG'G, AND MED., *supra* note 122, at 63-67.
143 *Id.* at 52-53.

at least partially, correct for the biases of peer review. But the resulting empowerment of program directors could prove counterproductive if the directors themselves are biased or lack critical information. After all, it is the directors who suggest the specific research programs in the first place. Bias among program directors is also of concern because many of them come from industry and return there after their interlude at ARPA-E and because they are recruited from a relatively close-knit professional community.[144] Besides, ARPA-E's culture requires program directors "to exert religious zeal in advancing selected technologies through the implementation stage."[145] Although not definitive, the fact that "[s]ignificant variation in project outcomes can be seen across ARPA-E programs"[146] suggests that some directors have been more successful than others.

Even if ARPA-E's decision-making process was perfect, many people, and particularly conservatives, will be skeptical of giving a small group of bureaucrats and scientists discretion over the allocation of large sums of taxpayer dollars. Despite the National Academy's overall positive report, the conservative Heritage Foundation has argued that ARPA-E has been captured by various special interest groups and that it wastes precious tax dollars by funding projects that would otherwise be funded privately.[147] Although the Government Accountability Office investigated this claim and found "that most ARPA-E-type projects could not be funded solely by private investors,"[148] the Trump administration has signaled that it may attempt to eliminate ARPA-E's funding.[149]

3. A Prediction Market for Transformative Energy Projects

Prediction markets could complement the group deliberation and peer review processes currently in place at ARPA-E and address some

[144] *See id.* at 56.

[145] Bonvillian & Van Atta, *supra* note 123, at 489.

[146] NAT'L ACADS. OF SCIS., ENG'G, AND MED., *supra* note 122, at 103-04.

[147] *See* HERITAGE FOUND., BLUEPRINT FOR BALANCE: A FEDERAL BUDGET FOR FISCAL YEAR 2018, at 61 (2017).

[148] U.S. GOV'T ACCOUNTABILITY OFFICE, GAO-12-112, DEPARTMENT OF ENERGY: ADVANCED RESEARCH PROJECTS AGENCY-ENERGY COULD BENEFIT FROM INFORMATION ON APPLICANTS' PRIOR FUNDING 12-14 (2012).

[149] *See* Christa Marshall, *Fears Rise About ARPA-E's Future Under Trump*, E&E NEWS: GREENWIRE (Feb. 3, 2017), https://www.eenews.net/stories/1060049535; Brad Plumer, *Scientists Praise Energy Innovation Office Trump Wants to Shut Down*, N.Y. TIMES (June 13, 2017), https://www.nytimes.com/2017/06/13/climate/arpa-e-national-academy-sciences.html.

of the concerns outlined above by forecasting the likelihood of success of ARPA-E's projects. They might also assuage the agency's conservative critics who tend to have more faith in markets as sources of information than in scientists and bureaucrats.

Neither energy technologies nor agency procedures are easily transformed overnight. Accordingly, we begin with a modest proposal for incremental change to ARPA-E's project selection process intended to jumpstart experimentation with prediction markets. Imagine that ARPA-E is considering applications received in response to an FOA for projects related to efficient gasoline engine design.[150] Program officials could set up a prediction market for each application to forecast the project's likelihood of success. They would need to define exactly what success means for each proposal and establish a date and metric by which success or failure would be determined.[151] One possibility requiring little deviation from current practice would be to define success as a determination made by ARPA-E at the end of the funding period that the project has met its milestones. Given that milestones are negotiated after an application is accepted and that these milestones are sometimes revised during the project, traders would implicitly have to predict what the milestones will be, but ARPA-E decision makers currently do this when they select applications for funding. Another possibility would be to have the market predict whether a project will be canceled prior to completion for failure to achieve its milestones.

Once success is defined, traders would bet on the outcome, receiving $1 per contract if the project succeeds and nothing if it fails. Bets would be conditioned on ARPA-E awarding the grant and would be canceled otherwise.[152] To avoid public disclosure of confidential information contained in grant applications, officials could limit participation in the market to ARPA-E employees and outside experts who participate in the ARPA-E peer review process. To avoid running afoul of gambling laws, the market could be based on play money with winners receiving prizes and bragging rights. Alternatively, ARPA-E could provide participants with an initial stake so that they are not

[150] *See, e.g.*, *Efficient Engine Design*, ARPA-E, https://arpa-e.energy.gov/?q=slick-sheet-project/efficient-engine-design (last visited Nov. 14, 2018).

[151] For prediction markets to function properly, outcomes must be clearly defined and rules of adjudication stable. Wolfers & Zitzewitz, *Prediction Markets*, *supra* note 62, at 120.

[152] The unwinding approach to conditional prediction markets has proven commercially feasible. MICHAEL ABRAMOWICZ, PREDICTOCRACY: MARKET MECHANISMS FOR PUBLIC AND PRIVATE DECISION MAKING 142 (2007) [hereinafter PREDICTOCRACY].

putting their own money at risk,[153] or traders could participate in a lottery offering prizes with raffle tickets allocated in proportion to prediction accuracy.[154]

We admit that the experimental use of prediction markets we propose here would have no more than a limited impact. The underlying mechanism, however, has the potential to provide valuable information to ARPA-E decision-makers. The clearing price for each prediction market would aggregate the views of highly trained experts to deliver a transparent and convenient forecast. The ability to trade anonymously would further encourage truthful predictions and mitigate some of the biases that afflict group deliberation and peer review.

More importantly, smaller-scale experimentation with this type of low-risk prediction market could pave the way for more ambitious efforts going forward. Like any new tool in the administrative toolkit, prediction markets must first prove themselves before they can become a routine part of the policymaking process. Importantly, ARPA-E could immediately implement the mechanism proposed here at low cost and without the need for further enabling legislation. Once officials recognize the value added by prediction markets, they can resort (and defer) to them more often. In the long term, experimentation can create an empirical track record that facilitates ongoing improvements to prediction market design and implementation.

4. A Prediction Market for ARPA-E Programs

By limiting participation to a small group of experts and government officials, our proposal for project prediction markets fails to unlock the full potential of markets to aggregate widely dispersed information and to amalgamate diverse viewpoints. The simplest way to address this concern would be to open project prediction markets to the public. Grant applications may, however, contain confidential information and public disclosure could jeopardize an applicant's ability to patent inventions flowing from the grant. This might not discourage all applications, but the concern is significant enough to raise questions about the usefulness of this type of prediction market.

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[153] *See* Tom W. Bell, *Government Prediction Markets: Why, Who, and How*, 116 PA. ST. L. REV. 403, 418 (2011).

[154] *Cf.* SUNSTEIN, INFOTOPIA, *supra* note 44, at 117 (describing how Microsoft has used markets of this type).

An alternative approach would be for ARPA-E to set up prediction markets to guide the allocation of large blocks of money. These prediction markets would be open to the public and based on real money. As discussed above, under current practice, ARPA-E periodically identifies particular program areas worthy of grant funding and then solicits specific project proposals. This process could easily incorporate prediction markets to identify particularly promising program areas. The agency could, for example, propose to issue $50 million in grants related to carbon capture research.[155] Prediction markets would then forecast whether the proposal would likely succeed in reaching the agency's pre-determined research objective.

A few technical points are worth noting. The first relates to the question of what outcome these prediction markets should focus on as the measure of a proposal's success. Ideally, the market would predict whether the proposal would affect some comprehensive measure of social welfare that might include economic productivity as measured by GDP and other welfare indices designed to measure environmental quality, health, and happiness.[156] It will be difficult, however, to obtain agreement on how to measure social welfare. Furthermore, even if everyone agreed on the appropriate metric, in practice, the measure would no doubt prove noisy so that only proposals expected to generate very significant consequences would produce any measurable effect.[157] As a result, prediction markets might be of little use in assessing less consequential proposals even if those proposals might produce substantial net benefits in the long run or serve as stepping stones for more transformative research.[158]

Program-level prediction markets could address this challenge through more narrowly defined outcome measures.[159] For proposals

[155] Funding for focused technology programs typically ranges from thirty to fifty million dollars and is allocated among five to fifteen projects. Manser et al., *supra* note 120, at 987.

[156] *Cf.* Hanson, *Bet on Beliefs*, *supra* note 99, at 152 (arguing for the adoption of policies that, according to prediction markets, would improve national welfare).

[157] One way to deal with noisy predictions would be to use a prediction market to predict the difference between prices in two other prediction markets, one of which is conditioned on adoption of a policy and the other on failure to adopt. *See* ABRAMOWICZ, PREDICTOCRACY, *supra* note 152, at 203.

[158] Nonetheless, even measures that are noisy can be useful for evaluation of proposals. *See* Hanson, *Bet on Beliefs*, supra note 99, at 173-74.

[159] *Cf. id.* at 171 (demonstrating the utility of "more focused welfare measures" by noting how a stadium policy could have different impacts on national and regional welfare).

that focus on technologies designed to curb climate change, an obvious option would be to forecast their effects on carbon emissions. Even more narrowly, the markets could forecast intermediate metrics of success such as citations to funded research in academic journals or patent applications and the amount of follow-on funding that projects will receive.

Notice, however, that as the focus moves from broader to narrower measures of success, the relationship between the predicted outcome (e.g., carbon emissions or journal citations) and the ultimate outcome of interest (i.e., social welfare or environmental quality) becomes more tenuous and less politically palatable. Some conservatives, for instance, might object to markets that predict reductions in carbon emissions because they question the link between emissions and global warming.

The second technical point relates to the type of prediction market used.[160] A particularly promising approach would be for ARPA-E to use prediction markets to obtain a probability distribution for various values of the outcome of interest. For example, ARPA-E could issue contracts paying $1 if the U.S. transportation sector's carbon emissions are between 2 and 2.1 billion metric tons in 2030, conditioned on the government making a $100 million grant for research to develop a more efficient gasoline engine. It could issue similar contracts for emissions levels between 1.7 and 1.8 billion metric tons, 1.8 and 1.9 billion metric tons, and so forth. A similar set of markets could be conditioned on the absence of the grant. Comparing the resulting probability distributions for each set of markets would provide information not only about the proposal's expected effect on emissions, but also about the uncertainty of those expectations.[161]

Alternatively, as we suggested in the Introduction, the government could use prediction markets to predict the level of carbon emissions. Under this approach, a contract could pay $1 for each 100 million metric tons of emissions in the transportation sector in the year 2030. If such a contract were selling for $20, its price would imply a forecast of 2 billion metric tons. Again, ARPA-E could issue contracts conditioned on a grant for gasoline engine research and on the absence of the grant, and the difference in price would forecast the effect of the grant.

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[160] In prediction market parlance, we are proposing a family of winner-take-all contracts. For evidence that the approach we recommend can work, see Wolfers & Zitzewitz, *Prediction Markets*, *supra* note 62, at 114-15. For a discussion of other types of prediction markets, see generally *id.* at 109-10.

[161] *See id.* at 109-10.

Finally, ARPA-E could obtain additional information by varying the contingency on which a market is conditioned. It could, for example, establish prediction markets to forecast the effects of allotting money for carbon capture research conditioned on various levels of investment, e.g., $50 million, $100 million, or $150 million. These markets would provide guidance on the optimal amount of funding and its allocation.

B. Use of Prediction Markets by Congress

Thus far, we have proposed the use of prediction markets by a grant-making institution either to forecast the outcome of projects or to determine the research areas to which funds should be allocated. A potential criticism of our proposals is that they assume that grants are the best way to encourage clean technology innovation. Perhaps tax dollars would be better spent on technology inducement prizes or funding a clean technology research and development tax credit. It is a testament to the versatility of prediction markets that they can also help inform the choice among these competing policy options. To illustrate, Congress could set aside $10 billion to fund clean technology research. It could draft specific proposals to distribute the money via prizes or grants made by grant-making institutions or to use it to fund a clean technology R&D tax credit.[162] Prediction markets could then forecast the effects of these proposals on carbon emissions or another outcome of interest. In fact, multiple market predictions could be combined to determine the optimal mix of policies.

C. Caveats and Criticisms

Any proposal as daring and far-reaching in its consequences as the use of prediction markets to guide climate policy will inevitably elicit criticism. This section addresses potential criticisms and adds some important caveats.

[162] For a discussion of the various ways in which the government could subsidize clean energy, see generally David Popp, *Innovation and Climate Policy*, 2 ANN. REV. RESOURCE ECON. 275 (2010). Michael Abramowicz has suggested to us the intriguing possibility that the government could use ex post subsidies as an alternative to prediction markets in some instances. The government would announce that it plans to pay out in the future some amount of subsidy for clean technology and then private capital markets would direct investment toward technologies that investors believe the government would likely reward.

1. Market Manipulation and Trader Biases

Perhaps the most obvious concern with using prediction markets to guide public policy is that parties with a financial interest in a policy might bet heavily on their favored outcome to manipulate the result. Some of the markets that we have proposed would not be open to the public. Participation would be limited to a few experts and government officials and the dollar amounts involved would be small so that manipulation should not be a major problem. But limiting participation comes at the cost of losing potentially valuable input from those unable to participate. On the other hand, manipulation is a critical concern for any market open to the public. Coal companies, for example, might bet in a way that steers subsidies toward carbon capture research, not because they consider carbon capture to be a sound investment, but because they stand to gain if the subsidies pay off, and they will not bear the full cost of failure.

The only way to determine whether the risk of manipulation is a fatal flaw is through experimentation. The limited evidence to date suggests that sustained manipulation of prediction market prices is difficult, albeit perhaps not impossible.[163] There are, however, reasons for optimism. By trading based on something other than the estimated value of the underlying contract, would-be manipulators function as noise traders. Noise traders effectively subsidize speculative markets by providing profit opportunities to traders who are better informed about fundamental values. In particular, arbitrageurs can profit from manipulators by taking their bets, thereby foiling their attempts at manipulation. Paradoxically, manipulators can even make prediction markets more accurate by giving better informed traders an extra incentive to participate.[164]

In addition, the risk posed by manipulation depends on the circumstances.[165] In markets where trader forecasts are based on

[163] For recent reviews of the literature, see generally Joyce E. Berg & Thomas A. Rietz, *Market Design, Manipulation, and Accuracy in Political Prediction Markets: Lessons from the Iowa Electronic Markets*, 47 PS: POL. SCI. & POL. 293 (2014); Cary Deck et al., *Affecting Policy by Manipulating Prediction Markets: Experimental Evidence*, 85 J. ECON. BEHAV. & ORG. 48, 49-50 (2013); Simon Kloker & Tobias T. Kranz, Manipulation in Prediction Markets: Chasing the Fraudsters (June 10, 2017) (unpublished manuscript), https://aisel.aisnet.org/ecis2017_rip/47/.

[164] *See* Robin Hanson & Ryan Oprea, *A Manipulator Can Aid Prediction Market Accuracy*, 76 ECONOMICA 304, 305 (2009).

[165] For conditional prediction markets, the expected cost of manipulation decreases with the likelihood that the condition will be met. *See* Lionel Page, *The Ability of Markets to Predict Conditional Probabilities: Evidence from the U.S. Presidential Campaign*, *in* PREDICTION MARKETS: THEORY AND APPLICATIONS *supra* note 63, at 123,

publicly available information and traders do not have private information bearing on the outcome of interest, manipulation should be less of a problem because an arbitrageur has no reason to believe that recent trades are based on information that she herself does not possess. As a result, she will be more likely to make trades that correct the market price. Moreover, even where some traders have private information, other traders may be able to counteract manipulation attempts if they know that incentives for manipulation exist.[166]

A related concern is that traders might suffer from biases that could affect the market price.[167] But here again there is cause for optimism. Studies of election prediction markets have found that those markets make remarkably accurate predictions even though traders are not representative of voters generally and many traders suffer from numerous biases, including excessively optimistic expectations of their preferred candidates.[168] These markets function well because, at the margin, the market price is determined by a small but well-informed and less biased group of active traders who profit by taking advantage of the partisans.[169] Unlike group deliberation or polls in which numbers matter most, a small number of informed and confident traders can drive outcomes in prediction markets.

2. Thin Markets

A market with little trading activity might not produce a reliable price signal.[170] Thin, illiquid markets could be a problem particularly when the government creates multiple, related prediction markets on the same topic.

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135. In the policy context, manipulation might be a problem for advisory markets where traders believe that the policy is unlikely to be adopted.

166 *See* Robin Hanson et al., *Information Aggregation and Manipulation in an Experimental Market*, 60 J. ECON. BEHAV. & ORG. 449, 458 (2006).

167 *See, e.g.*, William N. Goetzmann & Massimo Massa, *Daily Momentum and Contrarian Behavior of Index Fund Investors*, 37 J. FIN. & QUANTITATIVE ANALYSIS 375, 379-81 (2002) (finding evidence of biased behavior among investors in a stock index fund).

168 Berg et al., *Results*, *supra* note 79, at 742-49.

169 *See id.* at 749.

170 *See* Ledyard, *supra* note 62, at 61. Note, however, that empirical evidence suggests that even thin markets can sometimes perform well. *See* Wolfers & Zitzewitz, *Prediction Markets*, *supra* note 62, at 113-14. Moreover, prediction market technicians have developed mechanisms for producing accurate predictions even in thin markets. *See, e.g.*, Robin Hanson, *Combinatorial Information Market Design*, 5 INFO. SYS. FRONTIERS 107, 117-18 (2003).

When markets are limited to a small group of bureaucrats and experts, the government can improve market trading and liquidity by offering participants an incentive to trade, e.g., by giving them money with which to make bets or by offering prizes. Public prediction markets, on the other hand, should generate sufficient trading spontaneously so long as traders believe that the markets might actually influence policy. If the market related to a policy proposal is thin, interested parties could manipulate it by betting on their preferred outcome. In doing so, they would then become noise traders, and speculators could make money by betting against them in a self-reinforcing process that thickens the market.[171] Even if noise traders fail to materialize, the government can simply subsidize the market directly, e.g., by making random trades and thereby functioning as a noise trader or by subsidizing an automated market maker.[172] Another way to encourage market activity is to increase the importance of prediction markets by putting them directly in charge of decisions,[173] a possibility that we discuss in more detail below.

3. The Risks (and Benefits) of Insider Trading

Unlike stock markets, prediction markets aim to provide information. Therefore, insider trading can be a feature rather than a bug.[174] If prediction markets are open to the public and based on real money, then people who have inside information or a direct financial interest in the outcome should generally be allowed to trade along with government officials, as long as their ability to do so is well publicized.[175] The main concern here is that insider trading will discourage others from participating because they assume that insiders know more and will take advantage of them.[176] But that risk will be minimal in the public prediction markets that we contemplate because relevant information is likely to be widely dispersed. Insiders may have some additional information, but the information asymmetry

[171] Hanson, *Bet on Beliefs*, *supra* note 99, at 168.

[172] *See* Wolfers & Zitzewitz, *Prediction Markets*, *supra* note 62, at 121; Robin Hanson, *Prediction Markets "Fail" To Mooch*, OVERCOMING BIAS (July 19, 2012, 12:00 AM), http://www.overcomingbias.com/2012/07/prediction-markets-fail-to-mooch.html.

[173] *See* ABRAMOWICZ, PREDICTOCRACY, *supra* note 152, at 211-13.

[174] *Cf.* HENRY G. MANNE, INSIDER TRADING AND THE STOCK MARKET (1966) (arguing that permitting insider trading with respect to stocks would promote efficiency by ensuring that stock prices incorporate private information).

[175] *Cf.* Henderson et al., *supra* note 65, at 54-55 ("[W]e would suggest that there should be a presumption against ever limiting participation in markets.").

[176] *Id.* at 55.

should not be severe. To the extent information asymmetry is significant for a given market, Robin Hanson has proposed a mechanism for dealing with it. Insiders would be allowed to trade, but their trades would be disclosed in advance.[177] As a last resort, if there is a risk that arbitrageurs cannot overcome the risk of manipulation by insiders, then a ban on insider trading might be appropriate, though it may impair market accuracy.

4. Correlation Is Not the Same as Causation

If conditional prediction markets are advisory rather than binding, then policymakers must be careful not to confuse correlation with causation.[178] To illustrate the potential problem, consider a scenario where prediction market prices suggest that future carbon emissions will be substantially lower if the government heavily subsidizes carbon capture technology. Unfortunately, policymakers cannot simply conclude that traders believe that increasing the carbon capture subsidy will cause the reduction in emissions.

If the government has private, policy-relevant information, then traders will try to account for this information asymmetry in their forecasts.[179] Specifically, traders may conclude that policymakers will increase the carbon capture subsidy only if policymakers have information that supports doing so. In that case, the market's prediction of future emissions conditioned on the subsidy may be biased downward to reflect the fact that the subsidy will occur only under favorable circumstances. Note, however, that this problem only arises if traders believe that policymakers have important private information, which will not always be the case. In any event, the government can mitigate this problem by allowing insiders with the same private information to participate in the market.[180] Another approach would be to place the decision in the hands of someone without private information, in which case that person would rely solely on the prediction market along with publicly disclosed expert reports.[181] Those with private information could still influence the

177 Robin Hanson, *Decision Markets for Policy Advice*, *in* PROMOTING THE GENERAL WELFARE: NEW PERSPECTIVES ON GOVERNMENT PERFORMANCE 151, 172 n.20 (Alan S. Gerber & Eric M. Patashnik, eds., 2006).

178 *See* Wolfers & Zitzewitz, *Prediction Markets*, *supra* note 62, at 123-24.

179 *See* Hanson, *Bet on Beliefs*, *supra* note 99, at 162; Page, *supra* note 165, at 133-34.

180 *See* Hahn & Tetlock, *supra* note 102, at 254-55; Hanson, *Bet on Beliefs*, *supra* note 99, at 162.

181 ABRAMOWICZ, PREDICTOCRACY, *supra* note 152, at 207.

decision by trading in the market or publicizing what they know for the benefit of the decision-maker. In addition, traders should be informed that the decision to adopt or reject the policy will be made during a short decision window preferably in the near future.[182] This will allay fears that new information might come to light before the market closes.

Even if the government has no private information bearing on a policy's likelihood of success, the adoption of the policy in question may still correlate with a change in the outcome of interest without being the sole cause of that change. For instance, traders may conclude that the government will increase the carbon capture subsidy only if the president decides to prioritize climate policy, a decision that would entail adoption of numerous complementary policies. In that case, the market may predict that emissions will fall if the carbon capture subsidy increases, but only because traders expect the overall package of climate policies to be effective, not necessarily because they believe that carbon capture itself will succeed.

In the abstract, this latter problem presents a significant challenge to the use of advisory prediction markets. But if, as should often be the case, policymakers have no reason to suspect problems of reverse causation or omitted variable bias,[183] they can more confidently rely on prediction market forecasts. Moreover, prediction market technicians have developed sophisticated methods for disentangling correlation and causation.[184] Due to space constraints, we will not discuss these methods in detail. Suffice it to say that the problem of using prediction markets to draw conclusions about causation strikes us as no more daunting than the many challenges facing conventional decision-making mechanisms.

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[182] *See id.*

[183] Omitted variable bias may occur when a variable is omitted from a statistical analysis and that variable is correlated with the independent variable and an included dependent variable. SCOTT W. MENARD, LOGISTIC REGRESSION: FROM INTRODUCTORY TO ADVANCED CONCEPTS AND APPLICATIONS 107 (2010).

[184] *See, e.g.*, Henderson et al., *supra* note 65, at 47-50 (recommending the use of instrumental variables); Wolfers & Zitzewitz, *Prediction Markets*, *supra* note 62, at 122-24 (discussing the use of contingent contracts); Robin Hanson, *Shock Response Futures*, OVERCOMING BIAS (May 31, 2007, 6:00 AM), http://www.overcomingbias.com/2007/05/shock_response_.html (proposing shock response futures); *see generally* Eric Snowberg et al., *How Prediction Markets Can Save Event Studies*, *in* PREDICTION MARKETS: THEORY AND APPLICATIONS, *supra* note 63, at 18, 27-30 (discussing how incorporating prediction markets into event studies can facilitate causal inferences).

The simplest way to cope with the correlation-versus-causation problem would be to put decision markets directly in charge.[185] For example, the government could announce in advance that if prediction markets predict that $100 million in grants for carbon capture research will reduce emissions by *x* amount in 2030, then it will fund the grants.[186]

We recognize that self-deciding prediction markets of this type constitute a significant departure from current practice. We do not recommend them for important decisions absent further experimentation and a strong empirical record of success. Having said that, increased reliance on prediction markets might not be as risky as it seems. Currently, group deliberation, peer review, and cost-benefit analysis, despite their well-documented flaws, play a substantial role in policymaking, particularly within administrative agencies. Moreover, even if self-deciding prediction markets would occasionally make grave mistakes, these markets might, on balance, still improve on current institutions, which many argue frequently produce very costly errors.

Importantly, self-deciding prediction markets would not rule out the use of expert reports and committees or even cost-benefit analysis. In fact, experts could provide valuable information to traders. The real innovation of a self-deciding prediction market is that the market itself would serve as the decision maker rather than an individual or committee. The novelty of this approach provides good reason for caution. But neither theory nor empirical evidence supports an *a priori* claim that individuals or deliberating groups will always or usually make better policy decisions than prediction markets.

5. Longshot Bias

Numerous studies have found that sports gamblers bet excessively on longshots.[187] This could be because they enjoy taking risks or because they overestimate the likelihood of low-probability events.[188]

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185 *See* ABRAMOWICZ, PREDICTOCRACY, *supra* note 152, at 211; Hanson, *Bet on Beliefs*, *supra* note 99, at 162.

186 Because of the risk of brief price spikes, the government would likely not want to focus on the price at any given time, but instead average transaction prices over a longer period. *See* Abramowicz, *Information Markets*, *supra* note 102, at 946.

187 *E.g.*, Oikonomidis & Johnson, *supra* note 63, at 207-08 (reviewing the evidence related to soccer betting).

188 Erik Snowberg & Justin Wolfers, *Explaining the Favorite–Longshot Bias: Is It Risk-Love or Misperceptions?*, 118 J. POL. ECON. 723, 743-44 (2010) (finding evidence of the latter).

Evidence suggests that this longshot bias also has some effect on prediction markets in that extremely unlikely outcomes are overpriced, especially in thin markets.[189] If transaction costs are low, however, arbitrageurs should be able to minimize the damage by taking advantage of biased participants.[190] Moreover, longshot bias would not be a problem in prediction markets for climate policy unless the government adopted policies that markets suggested had an extremely low probability of success.

6. Asset Bubbles

Some economists believe that speculative markets are prone to bubbles during which assets are overvalued for a sustained period.[191] This hypothesis is controversial and difficult to prove. But even if bubbles do occur, we have reason to believe that they will not affect prediction markets to the same degree as other speculative markets.

First, in some speculative markets, bubbles may occur because investors who recognize that a bubble exists do not know exactly when it will burst and are unable or unwilling to put significant capital at risk until the market corrects itself.[192] In prediction markets, however, the amounts involved are often small enough that capital constraints should not influence traders' bets.[193] Moreover, when a prediction market is open for only a short period, that reduces the risk of a prolonged bubble and facilitates arbitrage.[194]

Second, stock market bubbles may occur because many investors follow trends so that if the market has been increasing, many assume it will continue to increase and buy accordingly, creating a self-fulfilling prophecy that ultimately proves unsustainable.[195] Most prediction markets, however, should not suffer from this problem

[189] *See* Wolfers & Zitzewitz, *Prediction Markets*, *supra* note 62, at 117-18.

[190] The government should set up prediction markets to facilitate arbitrage opportunities. *See* Richard Borghesi, *Price Biases and Contract Design: Lessons from Tradesports*, *in* PREDICTION MARKETS: THEORY AND APPLICATIONS, *supra* note 63, at 96, 105-08 (providing evidence from football prediction markets that properly designed contracts facilitate arbitrage and increase efficiency).

[191] *See, e.g.*, Robert J. Shiller, *From Efficient Markets Theory to Behavioral Finance*, 17 J. ECON. PERSP. 83, 96-101 (2003).

[192] *See* J. Bradford De Long et al., *Noise Trader Risk in Financial Markets*, 98 J. POL. ECON. 703, 704-06 (1990); Andrei Shleifer & Robert W. Vishny, *The Limits of Arbitrage*, 52 J. FIN. 35, 36-37 (1997).

[193] Wolfers & Zitzewitz, *Prediction Markets*, *supra* note 62, at 118.

[194] ABRAMOWICZ, PREDICTOCRACY, *supra* note 152, at 222-23.

[195] *See* Goetzmann & Massa, *supra* note 167, at 378-88 (discussing the influence of momentum traders on the stock market).

because they cannot move in the same direction indefinitely.[196] For example, the probability that an ARPA-E project will succeed can never exceed 100%.

Finally, in some speculative markets, bubbles may occur because of constraints on short selling.[197] But in prediction markets, there are no constraints on short selling, and there are even mechanisms that substitute for short selling.[198]

Despite these reasons for optimism, the only way to determine whether the prediction markets that we propose are prone to bubbles is through experimentation. Even if bubbles do occur on occasion, the question is whether other forecasting mechanisms consistently perform better. Empirical evidence to date is encouraging: while prediction markets are subject to bubbles, the problem has not proven to be widespread or significant.[199]

7. Time Discounting

Some of the prediction markets that we envision would have long time horizons because the outcomes of interest would not occur until years (maybe even decades) into the future. Long time horizons can be problematic because during the time they hold contracts, traders forgo the return that they would otherwise earn on any invested funds. As a result, people become less willing to participate in the market, and the market price is distorted, reducing the market's ability to yield useful information.[200] Fortunately, market operators can overcome this problem by allowing traders to put their money in a self-directed investment fund so that they can assemble the portfolio of their choice, making them indifferent between investing in prediction markets or more traditional markets.[201] Moreover, prediction markets

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196 *See* ABRAMOWICZ, PREDICTOCRACY, *supra* note 152, at 218-19.

197 *See* Shiller, *supra* note 191, at 98-100.

198 *See* ABRAMOWICZ, PREDICTOCRACY, *supra* note 152, at 223; Wolfers & Zitzewitz, *Prediction Markets*, *supra* note 62, at 118. For empirical evidence that short selling increases prediction market accuracy, see generally Florian Teschner et al., *Short-Selling in Prediction Markets*, 5 J. PREDICTION MKTS., no.2, 2011, at 14.

199 *See, e.g.*, Wolfers & Zitzewitz, *Prediction Markets*, *supra* note 62, at 118-19.

200 *See* Werner Antweiler, *Long-Term Prediction Markets*, 6 J. PREDICTION MKTS., no. 3, 2012, at 43, 60; Lionel Page & Robert T. Clemen, *Do Prediction Markets Produce Well-Calibrated Probability Forecasts?*, 123 ECON. J. 491, 510-11 (2012).

201 Antweiler, *supra* note 200, at 58-59. For commercial prediction markets, investors might be concerned about the risk of bankruptcy or of adverse regulatory actions. *See id.* at 60. But for our proposal, these concerns are less significant because the markets in question would be government sanctioned.

for climate policy do not have to be perfectly efficient to yield useful information, particularly if the contract price suggests that a policy will have significant effects.[202] Under those circumstances, policymakers would benefit from the market's forecast even if the contract price was somewhat distorted.

8. Legal Concerns

We have recommended some prediction markets that would involve real money and be open to the public. A major impediment to these markets is that they may run afoul of state gambling laws or could be subject to stifling federal regulation as commodities futures markets.[203] We agree with others who have argued that government-sponsored prediction markets should not be subject to these restrictive laws,[204] but we also acknowledge that some of the prediction markets that we propose probably cannot legally operate without changes to existing regulations and perhaps even legislation. Having said that, legal concerns pose less of an obstacle to prediction markets such as those we suggest for ARPA-E, in which participation would be limited to government employees and consultants using play money or where the government supplies each participant with an initial stake in exchange for an obligation to trade.[205]

III. PREDICTION MARKETS TO INFORM STATE CLIMATE POLICIES

In the absence of comprehensive federal action to address climate change and promote clean energy, states are increasingly stepping in to fill the policy void.[206] Forty-five states and the District of Columbia have implemented net-metering policies that enable utility customers with solar and other distributed generation assets to effectively run their electricity meter backwards and be compensated for any power produced in excess of the customer's power consumption from the

[202] *Cf.* Vandenbergh et al., *supra* note 11, at 2006 (making a similar point with respect to prediction markets in general).

[203] For a discussion of the legal concerns surrounding real-money prediction markets, see Bell, *supra* note 153, at 417-25.

[204] *See, e.g.*, Kenneth J. Arrow et al., *The Promise of Prediction Markets*, 320 SCI. 877, 877-78 (2008); Bell, *supra* note 153, at 424-25.

[205] *See* Bell, *supra* note 153, at 428.

[206] For an overview of state climate policy action, see Engel & Orbach, *supra* note 13; Farber, *supra* note 13; Stewart, *supra* note 13; *see also* Mormann, *Clean Energy Federalism*, *supra* note 13 (exploring the ideal institutional level of implementation for select climate and clean energy policies).

grid.[207] Twenty-nine states, the District of Columbia, and three U.S. territories have adopted renewable portfolio standards[208] that create markets for low-carbon, renewable energy by requiring electric utilities to source a portion of their sales from solar, wind, and other low-carbon renewables.[209] A few pioneering states, meanwhile, have recently begun to experiment with feed-in tariff[210] policies that pay eligible generators above-market rates designed to cover the higher generation costs of emerging climate-friendly energy technologies.[211]

Every one of these state climate policies could benefit from prediction markets. Subtle differences in design and implementation notwithstanding, they all require policymakers and regulators to forecast some aspect of the future. As price-based policy tools,[212] feed-in tariffs require policymakers to anticipate the pace of technology learning and cost improvements over time to set and maintain

[207] Richard L. Revesz & Burcin Unel, *Managing the Future of the Electric Grid: Distributed Generation and Net Metering*, 41 HARV. ENVTL. L. REV. 43, 46-47 (2017).

[208] Renewable portfolio standards, also known as a renewable targets or quota obligations, set quotas that require electric utility companies to source a certain share of the electricity they sell to end-users from renewable sources of energy. *See infra* Part III.B.

[209] *See* NC CLEAN ENERGY TECH. CTR. & DEP'T OF ENERGY, RENEWABLE PORTFOLIO STANDARD POLICIES (2016), http://ncsolarcen-prod.s3.amazonaws.com/wp-content/uploads/2014/11/Renewable-Portfolio-Standards.pdf [https://perma.cc/B73L-ZKTT]. Eight more states and one U.S. territory have adopted nonbinding goals for the deployment of renewables. *See id.* For a discussion of the history and political background of state renewable portfolio standards, see Barry Rabe, *Race to the Top: The Expanding Role of U.S. State Renewable Portfolio Standards*, 7 SUSTAINABLE DEV. L. & POL'Y 10 (2007). For more information on the design and implementation characteristics of renewable portfolio standards, see *infra* Part III.B.

[210] Feed-in tariffs are two-pronged policies that guarantee renewable power generators access to their local power grid and require local electric utilities to purchase the power output of these generators at above-market rates. *See infra* Part III.A. The policy's misleading name — it does not impose any tariff on electricity imports or other related activities — is thought to be a tribute to an overly literal translation of its implementation in Germany as per the 1991 Stromeinspeisungsgesetz (Electricity Feed-in Law). *See* Paul Gipe, *Frequently Asked Questions about Feed-in Tariffs, Advanced Renewable Tariffs, and Renewable Energy Payments*, WIND-WORKS.ORG, http://www.wind-works.org/cms/index.php?id=211#c930 [https://perma.cc/S3HA-DECB].

[211] Early adopters of feed-in tariffs at the state level include California, Hawaii, Maine, Oregon, Rhode Island, Vermont, and Washington. *See infra* notes 215–21 and accompanying text. For more information on the design and implementation characteristics of feed-in tariffs, see *infra* Part III.A.

[212] *See* INT'L ENERGY AGENCY, DEPLOYING RENEWABLES: PRINCIPLES FOR EFFECTIVE POLICIES 92-93 (2008) [hereinafter DEPLOYING RENEWABLES] (explaining the dichotomy of price- and quantity-based policy tools to promote low-carbon renewable energy generation technologies).

appropriate tariff rates that offer sufficient but not excessive remuneration for eligible technologies. Quantity-based policies such as renewable portfolio standards let the market determine the level of remuneration but require policymakers to forecast the amount of solar, wind, and other intermittent renewables that the grid will be able to absorb without jeopardizing the reliability of electric service. Recent controversies over the equity implications of net metering and calls for higher grid usage fees to end alleged cross-subsidization[213] ask policymakers to assess and weigh the present as well as future costs and benefits of low-carbon distributed power generation. Finally, all of these, and many other, climate policies require policymakers to forecast the potential of specific clean energy technologies to help mitigate global warming and climate change.

A. Feed-in Tariffs: What Rate Is Right?

Feed-in tariffs have historically been popular among European countries including Denmark, Germany, Portugal, and Spain.[214] In the United States, a growing number of pioneering states have recently adopted feed-in tariff programs to promote renewables, including California,[215] Hawaii,[216] Maine,[217] Oregon,[218] Rhode Island,[219] Vermont,[220] and Washington.[221]

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213 *See, e.g.*, Troy A. Rule, *Solar Energy, Utilities, and Fairness*, 6 SAN DIEGO J. CLIMATE & ENERGY L. 115, 129-47 (2014–2015) (discussing the public debate over the "fairness" of net metering policies).

214 *See* INT'L ENERGY AGENCY, DEPLOYING RENEWABLES, *supra* note 212, at 17. For further background, see generally David Grinlinton & LeRoy Paddock, *The Role of Feed-in Tariffs in Supporting the Expansion of Solar Energy Production*, 41 U. TOL. L. REV. 943, 949-52 (2010). More recently, many jurisdictions outside of Europe have adopted feed-in tariffs to promote renewable energy, including the Canadian province of Ontario, South Africa, Kenya, the Indian states of West Bengal, Rajasthan, Gujarat, and Punjab, as well as Australia's Capital Territory, New South Wales, and South Australia. *See* MIGUEL MENDONÇA ET AL., POWERING THE GREEN ECONOMY: THE FEED-IN TARIFF HANDBOOK 90, 97-100, 102-08 (2010).

215 CAL. PUB. UTIL. CODE § 399.20 (2018).

216 *See* Stipulation for Protective Order at 1, Public Utilities Commission of Haw. (2009) (No. 2008-0273), https://perma.cc/E835-EVXC.

217 *See* ME. STAT. tit. 35-A, § 3603 (2015).

218 *See* OR. REV. STAT. § 757.365 (2016); Order 10-198 Establishing Pilot Program, Public Utility Commission of Oregon (2010); Order 10-200 Adopting New Rules, A Rulemaking Regarding Solar Photovoltaic Energy Systems (2010); Order 11-339 Modifying Pilot Program, Public Utility Commission of Oregon (2011).

219 *See* 39 R.I. GEN. LAWS §§ 39-26.1, 39-26.2 (2016).

220 *See* VT. STAT. ANN. tit. 30, § 8005a (2018).

221 *See* WASH. ADMIN. CODE § 458-20-273 (2018); WASH. REV. CODE § 82.16.110

Structurally, feed-in tariffs are best understood as two-pronged policy instruments.[222] The "feed-in" prong guarantees renewable power generators access to the electric grid to ensure viable sales and distribution channels for their power output. The "tariff" prong requires local electric utilities to purchase the electricity output of these generators at above-market rates that are designed to cover the generator's cost and offer a reasonable return on investment.[223] Tariffs can be set as a fixed total price for electricity from renewables, a premium to be paid in addition to the market price, or a percentage of retail rates.[224] Like portfolio standards and net metering policies, feed-in tariff policies allow electric utilities to pass the costs of premium payments for low-carbon renewable energy on to their ratepayers.[225] Feed-in tariffs are usually technology-specific, offering different tariff rates for different strands of renewable energy technologies based on their respective technological maturity and generation costs.[226] In addition, feed-in tariff design can be size-sensitive to account for the different cost structures of utility-scale and distributed generation.[227]

While renewable portfolio standards let the market determine trading prices for renewable energy credits and, hence, the overall

(2011).

222 *See* Wilson H. Rickerson et al., *If the Shoe FITs: Using Feed-in Tariffs to Meet U.S. Renewable Electricity Targets*, 20 ELECTRICITY J. 73, 73 (2007). For a detailed description of the various feed-in tariff design elements, see MENDONÇA ET AL., *supra* note 214, at 15-38.

223 The first-ever feed-in tariff in the United States, implemented by the municipality of Gainesville, Florida, was designed to offer a return on investment of five to six percent. *See* KARLYNN CORY ET AL., NAT'L RENEWABLE ENERGY LAB., TP-6A2-45549, FEED-IN TARIFF POLICY: DESIGN, IMPLEMENTATION, AND RPS POLICY INTERACTIONS 9 (2009), https://perma.cc/XSE7-EX5Z. The duration of the utility's purchase obligation under a feed-in tariff ranges from eight years in Spain to fifteen years in France to twenty years in Germany. Dominique Finon, *Pros and Cons of Alternative Policies Aimed at Promoting Renewables*, 12 EUR. INV. BANK PAPERS, *supra* note 1, at 115.

224 The second option is sometimes referred to as a "feed-in premium" or "premium feed-in tariff." *See* MENDONÇA ET AL., *supra* note 214, at 40. For an example of the retail rate percentage option, see Lucy Butler & Karsten Neuhoff, *Comparison of Feed-in Tariff, Quota and Auction Mechanisms to Support Wind Power Development*, 33 RENEWABLE ENERGY 1854, 1855 (2008). This Article generally refers to all of these options uniformly as feed-in tariffs.

225 *See* MENDONÇA ET AL., *supra* note 214, at 29.

226 *See id.* at 26. For an example of cost reductions through technology learning in solar photovoltaics and onshore wind energy, see INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, SPECIAL REPORT ON RENEWABLE ENERGY SOURCES AND CLIMATE CHANGE MITIGATION: SUMMARY FOR POLICYMAKERS 12-13 (Ottmar Edenhofer et al. eds., 2011) [hereinafter RENEWABLE ENERGY].

227 *See* MENDONÇA ET AL., *supra* note 214, at 26-27.

value of renewable electricity, feed-in tariffs require regulators to set tariff rates.[228] A tariff set too low will fail to attract the necessary investment to deploy renewable energy technologies, as the example of Argentina illustrates. In response to political opposition, Argentina's 2006 feed-in tariff for wind energy was set too low to leverage any investment, with deployed wind capacity stagnant at only thirty megawatts nationwide — the equivalent of thirteen present-day onshore wind turbines.[229] In the United States, the city of Palo Alto, California experienced similar issues when its solar feed-in tariff rates failed to incentivize any deployment during the first three years following its adoption in 2012.[230]

At the other end of the spectrum, a tariff set too high will impose undue hardship on electricity ratepayers and undermines public support for renewables, as evidenced by Spain's feed-in tariff for solar photovoltaics. The Spanish regulators chose to adopt rates similar to Germany's (then) widely praised feed-in tariff only to learn that, in real terms, these rates were far too high given sunny Spain's sixty percent greater insolation compared to cloudy Germany.[231] The Spanish policymakers' mishap delivered sizeable windfall profits to solar power investors while imposing considerable costs on the country's ratepayers, eroding the public's support for renewables and eventually forcing the Spanish government to suspend its feed-in tariff program.[232]

Even when policymakers get the initial feed-in tariff rate right, vigilant regulatory oversight and frequent adjustments are needed to ensure that tariff rates keep up with cost improvements in renewable energy technologies. Growth in deployed capacity enables technology learning that, in turn, reduces generation costs and moves low-carbon renewable energy technologies closer to grid parity.[233] Along the way,

[228] See *id.* at 19.

[229] *See id.* at 57.

[230] Mormann, *Clean Energy Federalism, supra* note 13, at 1661.

[231] *See* MENDONÇA ET AL., *supra* note 214, at 58-59.

[232] *See The Government Will Temporarily Suspend Premiums for New Special Regime Facilities*, MINISTRY INDUSTRY, ENERGY, & TOURISM (Jan. 27, 2012), http://www.minetur.gob.es/en-US/GabinetePrensa/NotasPrensa/2012/Paginas/npregimenespecial270112.aspx (last visited Feb. 12, 2018) (Spain).

[233] Technology learning and cost-reduction varies by technology dependent upon the level of market maturity. Solar photovoltaics, for instance, has historically experienced cost reductions of twenty-two percent for every doubling of capacity. The cost of onshore wind energy facilities has come down by ten percent for every doubling of capacity. PATRICK HEARPS & DYLAN MCCONNELL, RENEWABLE ENERGY TECHNOLOGY COST REVIEW 15, 26 (2011).

feed-in tariffs require constant monitoring and modification to keep investor returns reasonable and avoid windfalls from tariffs that, for example, fail to fall along with tumbling prices for solar panels.[234]

State-level feed-in tariffs in the United States, such as that of Oregon, give testament to the considerable demands that these policies place on policymakers and regulators in their quest to set, and maintain, appropriate tariff levels. Oregon's solar feed-in tariff,[235] also known as the Oregon Solar Photovoltaic Volumetric Incentive Program, launched on July 1, 2010, offering tariff rates of up to $0.65 per kilowatt-hour of solar-generated electricity.[236] The program was soon criticized for setting rates that were much too high, offering windfall profits to developers.[237] During initial enrollment rounds, available capacity was, indeed, oversubscribed within a matter of minutes, leading the Oregon Public Utility Commission to eventually convert capacity allocation from a first-come-first-served system to a lottery.[238]

To be fair, the regulators in charge of setting Oregon's feed-in tariff rates were given a tall task. Anticipating the real-world cost of solar and other low-carbon renewable energy generation projects and, hence, the level of remuneration that would cover these costs, while also offering a reasonable return — neither excessive nor insufficient — on the developer's investment is a complex undertaking. The magic number, often described as the levelized cost of electricity,[239] depends on a variety of factors, each subject to frequent and sometimes drastic

[234] *See* Felix Mormann et al., *A Tale of Three Markets: Comparing the Renewable Energy Experiences of California, Texas, and Germany*, 35 STAN. ENVTL. L.J. 55, 97 (2016) [hereinafter *A Tale of Three Markets*] (describing German policymakers' struggle to adjust the country's feed-in tariffs in response to rapid cost improvements for solar photovoltaic equipment).

[235] *See supra* note 218.

[236] *See* OR. PUB. UTIL. COMM'N., SOLAR PHOTOVOLTAIC VOLUMETRIC INCENTIVE PROGRAM: REPORT TO THE LEGISLATIVE ASSEMBLY 2-3 (2013).

[237] *See* Pub. Util. Comm'n of Or., Solar Voltaic Comments and Regulations, UM 1505, at 3 (2011) (statement of Dave Sullivan) ("The incentive rates were at least thirty percent too high to balance available capacity with demand.").

[238] *Cf. id.* at 4-5 (discussing a lottery system as a potential solution to the program's problems); OR. PUB. UTIL. COMM'N, *supra* note 236, at 15 (stating that for three enrollment periods, the program reached capacity in minutes).

[239] The levelized cost of electricity metric represents the cost per kilowatt-hour of electricity generated based on a power plant's capital costs, fuel costs, fixed and variable costs for operation and maintenance, and financing costs over the operational life of the plant. U.S. ENERGY INFO. ADMIN., LEVELIZED COST AND LEVELIZED AVOIDED COST OF NEW GENERATION RESOURCES IN THE ANNUAL ENERGY OUTLOOK 2018, at 1 (2018), http://www.eia.gov/forecasts/aeo/pdf/electricity_generation.pdf.

changes. The cost of solar panels, inverters, and other hardware, for example, has experienced a series of dramatic price drops over the past decade.[240] Soft costs, such as those incurred for permitting, installation labor, and capital, are subject to similar fluctuations, yet account for an ever-increasing share of overall project cost.[241] Finally, Oregon's regulators also had to consider site-specific factors like the variations in solar resource quality across different areas of their state.[242]

The vast amount of information required to set and maintain appropriate feed-in tariff rates illustrates the enormous potential for prediction markets to improve policy outcomes. Current practice requires public utility commissions, who often lack the necessary resources and expertise, to anticipate changes in solar panel prices, installation costs, lending rates, and other key inputs. Prediction markets offer a platform to aggregate pertinent information from industry experts, including manufacturers, installers, financiers and developers. Their "best guess" as to the levelized cost of solar electricity from, say, a residential rooftop facility in Portland six months from today, is likely to be considerably more accurate than that of even the most diligent utility commission. As discussed above, prediction markets could be structured to yield a probability distribution of the expected cost to help policymakers better understand the range of cost scenarios and their respective likelihood. As relevant information is widely disbursed, feed-in tariff prediction markets would function best if open to the public.

It is worth noting that the regulators in charge of Oregon's feed-in tariff program anticipated that they might err in setting tariff rates at the outset of the program. To address the problem, they incorporated an automatic rate adjustment mechanism, allowing tariff rates to rise or fall from one enrollment round to the next.[243] When demand far exceeds available capacity, the mechanism reduces the rate for the following round and, conversely, raises it if an enrollment round is

[240] *See, e.g.*, RAN FU ET AL., NAT'L RENEWABLE ENERGY LAB., TP-6A20-68925, U.S. SOLAR PHOTOVOLTAIC SYSTEM COST BENCHMARK: Q1 2017 vi (2017) (reporting cost declines of approximately thirty percent for utility-scale solar systems from 2016 to 2017).

[241] *See id.* at vi, viii (reporting soft costs as accounting for sixty-eight percent of overall costs in residential solar projects). For an introduction to soft costs and the factors driving them, see generally Felix Mormann, *Enhancing the Investor Appeal of Renewable Energy*, 42 ENVTL. L. 681, 704-10 (2012).

[242] As a tribute to regional variations in insolation, Oregon's feed-in tariff program divides the state into four different zones, each with its own rate. *See* OR. PUB. UTIL. COMM'N., *supra* note 236, 6-7 (2013).

[243] *See id.* at 6.

undersubscribed, originally in increments of ten percent, and later up to twenty percent.[244]

Automatic adjustment mechanisms for feed-in tariff rates have been adopted in other jurisdictions as well.[245] With their reliance on actual deployment data, these mechanisms are superior to the previously prevailing practice of randomly set annual degression rates.[246] Prediction markets, however, could dramatically improve upon automatic adjustment mechanisms.

From a timing perspective, automatic adjustments inevitably trail actual market developments because they react to previously observed deployment levels. Add to that the time it takes for the automatic price adjustment to become effective and it is easy to understand why automatically adjusted feed-in tariff rates are likely to lag behind actual cost characteristics, especially in markets as dynamic as those for solar and other emerging low-carbon energy technologies. Oregon's feed-in tariff has been criticized for this very reason, as it provides for automatic adjustments only every six months.[247] In contrast, prediction markets could aggregate information from knowledgeable parties into a well-informed forecast of what the levelized cost of solar electricity from a specific kind of project will be when the next enrollment window opens.

Automatic adjustment mechanisms also tend to lack necessary nuance when it comes to the magnitude of adjustments. Oregon's feed-in tariff program, for example, originally assumed that adjustments in increments of ten percent would be sufficient to track market developments.[248] At times of tumbling panel prices, however, downward adjustments of ten percent every six months may not be sufficient to keep up with steep declines in solar hardware costs. Subsequent program amendments allowed for automatic rate reductions of up to twenty percent. Such large increments, however, pose the inverse risk of excessive rate reductions. Sure enough, Oregon's mechanism eventually overdid its automatic rate reductions, as evidenced by the need to raise the feed-in tariff rate in April of 2012

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244 *Id.* at 7-8.

245 *See, e.g.*, CAL. ENERGY COMM'N, 2013 INTEGRATED ENERGY POLICY REPORT 59-60 (2013); Lincoln L. Davies & Kirsten Allen, *Feed-in Tariffs in Turmoil*, 116 W. VA. L. REV. 937, 955 (2014) (referencing Germany's "breathing cap").

246 *See supra* note 226 and accompanying text.

247 *See, e.g.*, Pub. Util. Comm'n of Or., Solar Voltaic Comments and Regulations, UM 1505 (2011) (statement of Dave Sullivan) ("This just isn't enough to keep up with the dynamic changes occurring in the marketplace.").

248 *See supra* note 244 and accompanying text.

following low deployment after an excessive twenty-percent reduction six months prior. Policymakers could avoid problems like those encountered by Oregon if they tied tariff rates to prediction market forecasts. In dynamic market environments, prediction markets are better suited to determine the direction and magnitude of rate adjustments than are clumsy automatic rate adjustment mechanisms.

B. Renewable Portfolio Standards: How Many Renewables Can the Grid Absorb?

Renewable portfolio standards create demand for solar, wind, and other low-carbon renewables by requiring electric utility companies to source a percentage of the electricity they sell to end-users from renewable sources.[249] Utilities prove their compliance with these requirements through "renewable energy credits."[250] Power plant operators normally receive one such credit for every megawatt-hour of electricity generated from renewable resources.[251] Non-utility power generators can sell their renewable energy credits to utilities in order to receive a premium on top of their income from power sales in the wholesale electricity market. Utilities can also invest in their own renewable power generation facilities to earn renewable energy credits for the electricity they produce. Whether utilities choose to earn their own credits or purchase them from others, they eventually pass the associated costs on to their ratepayers.[252]

Unlike feed-in tariffs that require regulators to set rates for eligible technologies, renewable portfolio standards trust the market's invisible hand to determine trading prices for renewable energy credits and, hence, a generator's overall revenue. While the market price is a function of demand and supply, policymakers indirectly affect it through the share of the electricity market they require utilities to serve with renewables. Requirements vary widely across states, from Ohio's modest 12.5% by 2026 mandate to fifty percent by 2030 in

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[249] *See* Reinhard Haas et al., *A Historical Review of Promotion Strategies for Electricity from Renewable Energy Sources in EU Countries*, 15 RENEWABLE & SUSTAINABLE ENERGY REVS. 1003, 1011-12 (2011).

[250] MENDONÇA ET AL., *supra* note 214, at 155; Hass et al., *supra* note 249, at 1012. Internationally, renewable energy credits are also referred to as tradable green certificates or renewable energy guarantees of origin.

[251] Lincoln L. Davies, *Power Forward: The Argument for a National RPS*, 42 CONN. L. REV. 1339, 1378 (2010) (reporting that some states award renewable energy credits for every kilowatt hour of renewable electricity generation).

[252] *See* Joshua P. Fershee, *Moving Power Forward: Creating a Forward-Looking Energy Policy Based on a National RPS*, 42 CONN. L. REV. 1405, 1410-12 (2010).

California and New York and all the way to a 100% renewable fueled electricity market in Hawaii by 2045.[253] These numbers are the product of a wide range of inputs, including political forces, resource availability and quality, ratepayer advocacy, and utility interests, among others.

From a practical perspective, one of the most important questions for policymakers to resolve is how ramping up the share of solar, wind, and other weather-dependent renewables will affect the reliability of electric service. Critics of the large-scale build-out of solar and wind power often claim that the intermittent output profiles of these renewable resources will jeopardize the stability of the electrical grid. According to one commentator, for example, "[w]hen renewables supply 20 to 30 percent of all electricity, many utility-energy engineers predict, the system will no longer be able to balance supply and demand."[254] Empirical evidence from across the globe suggests, however, that the grid can likely absorb larger quantities of intermittent renewables. Germany, for example, tripled the share of solar and wind power in its electricity mix between 2006 and 2013 to twenty-six percent, "while managing to reduce average annual outage times."[255]

But is there a limit? And, if so, how high is it? The answer to this critical question will depend on numerous factors and is likely to vary across jurisdictions and, more importantly, electricity networks. With information on grid infrastructure, load profiles, and other crucial factors widely dispersed, prediction markets are well suited to help policymakers gain a better understanding of "their" grid's ability to accommodate a growing share of renewables with intermittent output characteristics. Prediction markets could, for example, forecast outage times conditioned on the required percentage of renewables in the energy mix.

C. Net Metering: What Are the Costs and Benefits of Distributed Generation?

Adopted by over forty states, net energy metering has become the primary mechanism for tracking and rewarding distributed renewable

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[253] NC CLEAN ENERGY TECH. CTR. & DEP'T OF ENERGY, *supra* note 209.

[254] Charles C. Mann, *What If We Never Run out of Oil?*, ATLANTIC (May 2013), http://www.theatlantic.com/magazine/archive/2013/05/what-if-we-never-run-out-of-oil/309294/?single_page=true.

[255] Mormann et al., *A Tale of Three Markets, supra* note 234, at 87 (emphasis omitted).

energy generation in the United States.[256] Notwithstanding some variation across programs, net energy metering generally allows an electric utility's customer to run her meter forward while consuming power from the grid and backward while feeding power, e.g., from solar panels on her rooftop, into the grid.[257] At the end of the billing period, the utility charges the customer for the amount of power consumed from the grid minus power generated onsite and fed into the grid.[258] So long as the customer generator, on balance, consumes more electricity from the grid than she feeds in, her locally generated power is effectively remunerated at the retail electricity rate, several times higher than what she could get on the wholesale power market.[259]

In recent years, net metering programs have come under attack by special interest groups.[260] Led by electric utilities, opponents argue that net metering enables wealthy homeowners with rooftop solar to effectively stop paying for vital network maintenance and upgrades despite using the grid to supply electricity to their homes when their solar panels do not produce enough energy to meet their demand.[261] Already, some states have introduced hefty grid usage fees for electricity customers with solar rooftop installations.[262] There is no

[256] *See* Revesz & Unel, *supra* note 207, at 47; *see also* RENEWABLE ENERGY POL'Y NETWORK FOR THE 21ST CENTURY, RENEWABLES 2017 GLOBAL STATUS REPORT 120, 123-24 (2017) (documenting the proliferation of net energy metering globally and in the United States).

[257] *See* EDISON ELEC. INST., SOLAR ENERGY AND NET METERING 1, 2 (2013), http://www.eei.org/issuesandpolicy/generation/NetMetering/Documents/Straight%20Talk%20About%20Net%20Metering.pdf; Revesz & Unel, *supra* note 207, at 46.

[258] *See, e.g.*, Steven Ferrey, *Solving the Multimillion Dollar Constitutional Puzzle Surrounding State "Sustainable" Energy Policy*, 49 WAKE FOREST L. REV. 121, 128-29 (2014).

[259] *See* NAÏM R. DARGHOUTH ET AL., LAWRENCE BERKELEY NAT'L LAB., NET METERING AND MARKET FEEDBACK LOOPS: EXPLORING THE IMPACT OF RETAIL RATE DESIGN ON DISTRIBUTED PV DEPLOYMENT 1-3 (2015), http://emp.lbl.gov/sites/all/files/lbnl-183185_0.pdf.

[260] *See, e.g.*, Diane Cardwell, *Solar Panel Payments Set Off a Fairness Debate*, N.Y. TIMES (June 4, 2012), http://www.nytimes.com/2012/06/05/business/solar-payments-set-off-a-fairness-debate.html; Hiroko Tabuchi, *Rooftop Solar Dims Under Pressure from Utility Lobbyists*, N.Y. TIMES (July 8, 2017), https://www.nytimes.com/2017/07/08/climate/rooftop-solar-panels-tax-credits-utility-companies-lobbying.html.

[261] For a thoughtful summary and critique of the fairness arguments leveled against net energy metering programs, see Rule, *supra* note 213.

[262] *See, e.g.*, Katie Fehrenbacher, *Nevada's New Solar Fees Have People Furious*, FORTUNE (Jan. 14, 2016), http://fortune.com/2016/01/14/nevada-solar-battleground/. Other states are looking to follow Nevada's example. *See, e.g.*, Mark Hand, *Utah Utility Wants to Triple Monthly Charges for Solar Customers*, THINKPROGRESS (Aug. 8, 2017,

doubt that net energy metering and other clean energy policies have important equity implications.[263] Even for a cause as worthy as climate change mitigation, well-to-do homeowners should not be free riding on the electric grid at the expense of lower-income households. Yet, the common practice of embedding grid usage fees in volumetric charges, when coupled with net metering, allows solar customers to significantly reduce, if not altogether eliminate, their contributions to grid maintenance and upgrades.

Some usage fee might, therefore, seem reasonable to prevent inequitable cross-subsidization from lower-income to higher-income ratepayers. But how high should such a fee be? To answer this question, regulators first need to determine how much of a cross-subsidy, if any, solar customers actually receive from non-solar customers. This seemingly simple exercise in basic arithmetic is complicated by the fact that solar and non-solar ratepayers alike benefit from net metering-funded solar installations. There is, in fact, evidence to suggest that solar ratepayers may provide a net benefit to the grid and, hence, be the ones who cross-subsidize their non-solar counterparts.[264] For example, rooftop solar and other low-carbon distributed energy resources not only help mitigate climate change but also reduce peak demand during the hottest hours of the day. California's net metering program, along with other incentives, has shaved thousands of megawatts off the state's peak demand load.[265] Peak shaving provides two key benefits to the grid. First, reductions in peak demand minimize, if not altogether eliminate, the need for so-called peaker plants — usually older, more polluting plants that can be dispatched at relatively short notice but have such high operating costs that they are not profitable other than at peak demand, when

4:37 PM), https://thinkprogress.org/new-fees-on-utah-solar-customers-e4c7c2507008/.

263 For a comparison of the equity implications across policies, see Felix Mormann, *Clean Energy Equity*, UTAH L. REV. (forthcoming 2019), *available at* http://ssrn.com/abstract=3295296.

264 *See, e.g.*, Joel B. Eisen & Felix Mormann, *Free Trade in Electric Power*, 2018 UTAH L. REV. 49, 59-62 (2018) (describing the benefits that distributed energy resources offer to the electric grid).

265 *Cf.* CAL. INDEP. SYS. OPERATOR, WHAT THE DUCK CURVE TELLS US ABOUT MANAGING A GREEN GRID 1, 3 (2016), http://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf. For evidence of similar peak-shaving benefits from distributed solar generation in Hawaii, see Jeff, *The California Duck Curve is Real and Bigger Than Expected*, GREENTECH MEDIA (Nov. 3, 2016), https://www.greentechmedia.com/articles/read/the-california-duck-curve-is-real-and-bigger-than-expected#gs.2OnI32U.

wholesale prices are highest.[266] As a result, peak shaving abates pollution and reduces wholesale prices to the benefit of all ratepayers. Second, peak shaving reduces the need for costly transmission maintenance and upgrades required to deliver electricity from often remotely sited power plants to load centers. Pioneering utilities are already embracing distributed generation as an opportunity to avoid investments in distribution infrastructure by calling upon the marketplace to supply alternatives to wire upgrades and expansions.[267]

Quantifying these and other benefits provided by net metering-funded distributed generation and determining the exact costs imposed on the grid has proven difficult.[268] In light of the plethora of inputs relevant to this calculus and the wide dispersion of relevant information, prediction markets offer an ideal methodology for demystifying the net value of rooftop solar and other distributed energy resources now and going forward. Amidst a heated debate with strong opinions but limited facts on both sides, prediction market forecasts could help state policymakers determine the appropriate level of solar usage fees, if any, to impose on solar electricity customers in their state. Prediction markets could, for example, forecast the capital needs for generation and transmission expansion conditioned on the implementation of a net metering program to promote solar and other low-carbon distributed generation. To provide a meaningful counterfactual, a second market could sell contracts for generation and transmission investment requirements for a baseline scenario without net metering.

[266] *See* PETER FOX-PENNER, SMART POWER: CLIMATE CHANGE, THE SMART GRID, AND THE FUTURE OF ELECTRIC UTILITIES 96 (2010).

[267] *See, e.g.*, Joel B. Eisen, *Demand Response's Three Generations: Market Pathways and Challenges in the Modern Electric Grid*, 18 N.C. J.L. & TECH. 351, 422-23 (2017) (discussing one example, the "Neighborhood Program," in which the New York utility Consolidated Edison is using distributed energy resources and other "non-wires" alternatives to avoid having to build new distribution system infrastructure).

[268] *See, e.g.*, Dan Haugen, *Minnesota Becomes First State to Set "Value of Solar" Tariff*, GREENTECH MEDIA (Mar. 14, 2014), https://www.greentechmedia.com/articles/read/minnesota-becomes- St. John first-state-to-set-value-of-solar-tariff#gs.IVyL8e4. For a more general discussion of value-of-solar tariffs, see generally MIKE TAYLOR ET AL., NAT'L RENEWABLE ENERGY LAB., TP-6A20-62361, VALUE OF SOLAR: PROGRAM DESIGN AND IMPLEMENTATION CONSIDERATIONS (2015).

D. The Trillion Dollar Question: Which Policies and Technologies Best Reduce Greenhouse Gases?

Policymakers across the globe have embraced climate change mitigation and adaptation as top priorities.[269] Now that the question *whether* to take action on climate change has been answered with a resounding "yes," the challenge of figuring out *how* to do so looms large. The stakes could hardly be higher. In the continental United States alone, millions are projected to be at risk from rising sea levels.[270] Annual adaptation costs are estimated at over $400 billion with the overall cost of relocation expected to exceed $14 trillion.[271] Over the next two decades, the worldwide capital needs of clean energy and energy efficiency projects are forecast to surpass $30 trillion.[272] Which public policy strategy is best suited to leverage such vast amounts of private-sector investment? And what technologies should be targeted as the most promising to reduce greenhouse gas emissions in time to limit global warming to the crucial 2-degree Celsius mark,[273] or the recently announced, even more ambitious goal of 1.5 degrees Celsius?[274]

The quest for the optimal policy strategy to combat climate change is in high gear. As of 2016, 126 countries had adopted one or more

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[269] To date, 180 of the 197 parties to the United Nations Framework Convention on Climate Change have ratified the 2015 Paris Agreement on Climate Change. *Paris Agreement: Status of Ratification*, UNITED NATIONS CLIMATE CHANGE, http://unfccc.int/paris_agreement/items/9444.php (last visited Oct. 10, 2018). Even the Trump administration appears to have abandoned its original plans to withdraw the United States from the Paris Agreement. *See* Emre Peker, *Trump Administration Seeks to Avoid Withdrawal from Paris Climate Accord*, WALL ST. J. (Sept. 17, 2017), https://www.wsj.com/articles/trump-administration-wont-withdraw-from-paris-climate-deal-1505593922.

[270] Mathew E. Hauer et al., *Millions Projected to Be at Risk from Sea-Level Rise in the Continental United States*, 6 NATURE CLIMATE CHANGE 691, 691 (2016).

[271] *Id.* at 693-94. For a more conservative estimate, see Robert J. Nicholls et al., *Sea-Level Rise and Its Possible Impacts Given a "Beyond 4ºC World" in the Twenty-First Century*, 369 PHIL. TRANSACTIONS ROYAL SOC'Y 1, 13 (2011) (pegging annual adaptation costs at $25-270 billion).

[272] *See* INT'L ENERGY AGENCY, WORLD ENERGY OUTLOOK 2016, at 22 (2016).

[273] *See* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS v (Thomas F. Stocker et al. eds., 2013) (discussing the importance of limiting global warming to no more than two degrees Celsius in order to avoid disastrous and irreparable damage to the global ecosystem). *See generally* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, RENEWABLE ENERGY, *supra* note 226, at 6-26 (discussing the opportunities and challenges associated with the ramp-up of low-carbon, renewable energy technologies).

[274] *See* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, GLOBAL WARMING OF 1.5 DEGREES: SUMMARY FOR POLICYMAKERS 6 (Valérie Masson-Delmotteet al. eds., 2018).

policies to promote renewable power generation, sixty-eight nations had implemented policies to decarbonize their transportation sectors, and twenty-one countries had heating and cooling policies in place.[275] Most policymakers appear to be following a trial-and-error approach, switching back and forth among different policies.[276] Many, such as Australia, France, and Japan, have adopted a multi-pronged approach combining two or more different policy measures.[277] The same trend can be observed among state policymakers in the United States with California, for example, mixing and matching no fewer than five different policy tools to promote low-carbon renewables.[278]

Two decades of national and international experimentation with climate and clean energy policy have produced two key insights. First, not all clean energy policies are created equal.[279] Second, there is no one-size-fits-all policy option. Instead, a policy's success depends on a wide range of location-specific factors, including energy market regulations, lending practices, permitting rules, taxation, and manufacturing, to name but a few.[280] With knowledge of this multitude of diverse and ever-changing factors widely dispersed across regulators, investors, and other stakeholders, prediction markets could serve as a valuable focal point for aggregating and weighing pertinent information to assess a policy's likelihood to succeed in a given jurisdiction.

The choice of policy should further be tailored to the suite of technologies a policymaker seeks to promote. All else being equal, renewable portfolio standards and other market-based policies tend to yield better results for more mature technologies, while emerging technologies fare better under a feed-in tariff or similar policy approach that does not add market risk to technology risk.[281] Effective

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275 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, RENEWABLE ENERGY POL'Y NETWORK, *supra* note 256, at 120.

276 *See* INT'L ENERGY AGENCY, DEPLOYING RENEWABLES, *supra* note 212, at 94-95; INT'L ENERGY AGENCY, DEPLOYING RENEWABLES: BEST AND FUTURE POLICY PRACTICE 147-48 (2011) [hereinafter RENEWABLES].

277 INT'L ENERGY AGENCY, RENEWABLES, *supra* note 276.

278 *See* Mormann et al., *A Tale of Three Markets*, *supra* note 234, at 77-80, 83.

279 *See, e.g.*, INT'L ENERGY AGENCY, RENEWABLES, *supra* note 276, at 130 ("Support policies for renewables work, but they do not all work equally well.").

280 *See* Felix Mormann, *Beyond Tax Credits: Smarter Tax Policy for a Cleaner, More Democratic Energy Future*, 31 YALE J. ON REG. 303, 320 (2014) ("Renewable energy markets, however, vary considerably at national, regional, and even local levels regarding, for example, the ease of project development, resource endowment, cost of capital, and other critical market conditions.").

281 *See* Mormann et al., *A Tale of Three Markets*, *supra* note 234, at 90-92.

climate policymaking, therefore, starts with identifying the technologies that promise the greatest reduction in greenhouse gas emissions. Even the most thoughtful policy strategy will only be as successful at mitigating climate change as the technologies it seeks to promote. The range of technologies is vast. Nuclear, solar, and wind power may be the most obvious low-carbon power generation options today, but ocean tidal, advanced geothermal, and other emerging technologies hold great promise for the future.[282] Moving beyond generation, advanced batteries, molten salt, flywheel, compressed air, and other storage technologies could go a long way toward decarbonizing the grid. Smart thermostats, building weatherization, and other energy efficiency technologies, meanwhile, could reduce the need for new generation infrastructure and accelerate the decommissioning of coal-fired and other high-carbon legacy generators.[283] No policymaker can be expected to maintain a working knowledge of these and other, constantly evolving technology options, nor should they have to rely solely on advice from a small group of possibly biased experts. Prediction markets could help policymakers answer the trillion-dollar question of which technologies, and policies, will deliver the greatest greenhouse gas emission reductions for their jurisdiction.

CONCLUSION

Global warming and sea level rise represent enormous challenges for our planet and for policymakers. Efforts to address our changing climate require difficult predictions, including high-stakes bets on which technologies will usher in the low-carbon future. Existing legal institutions and conventional decision-making methods are too flawed to be trusted with this Herculean task. With a strong track record of outperforming other forecasting mechanisms across a wide range of contexts, prediction markets could help resolve the current policy gridlock and foster a new generation of smarter climate policies. In particular, prediction markets can improve government decision making through more reliable and transparent forecasts that aggregate

[282] For an overview of these and other generation technologies, see generally DAVID J.C. MACKAY, SUSTAINABLE ENERGY: WITHOUT THE HOT AIR (2009).

[283] *See, e.g.*, Steven Chu, *Cleaning Up: Energy and Climate Bill Will Boost the Economy*, RICH. TIMES DISPATCH (July 22, 2009), http://www.timesdispatch.com/news/article_e5d2835d-c68e-5249-8cc4-7af214751182.html ("The quickest and easiest way to reduce our carbon emissions is to make our appliances, cars, homes and other buildings more efficient. In fact, energy efficiency is not just low-hanging fruit; it is fruit that is lying on the ground.").

widely dispersed information in an unbiased way untainted by interest group politics. They also have the potential to overcome resistance to climate change mitigation efforts, especially among market-oriented conservatives.

We have outlined only a few of the many opportunities for federal and state policymakers to incorporate prediction markets into the climate policy process. Some of our suggestions could be implemented immediately with no change in existing laws, while other, more radical proposals would require legislative action. The applications discussed in this Article are by no means exhaustive. In fact, our main goal is to alert policymakers to the near-infinite possibilities for prediction markets and to encourage widespread experimentation.

Prediction markets are an incredibly promising policy tool, but their potential will be realized only if policymakers are willing to use them. We recommend starting small, perhaps with a play-money market at ARPA-E. Smaller-scale experimentation can create an empirical track record that facilitates incremental improvements to prediction market design and implementation. As prediction markets gain acceptance in the climate policy world, policymakers can expand their reach, possibly even delegating certain decisions to the markets themselves.